CORN CROP COEFFICIENTS BASED ON GROWING DEGREE DAYS OR GROWTH STAGE

by

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Summary:

This study reports the results of observed corn growth stage data versus cumulative growing degree days calculated by various methods. Corn crop coefficient equations were developed from lysimeter data from western and southeastern Nebraska.

Keywords:

corn, crop coefficients, growing degree days, growth stage, evapotranspiration

ABSTRACT

New crop coefficient equations were developed for use in calculating corn evapotranspiration (ET) as a function of growth stage or fraction of total cumulative growing degree days. Growing degree days were calculated by a 50-90 F stress method. Growth stage parameters were those by Hanway (1971). The corn crop coefficients are basal or minimal coefficients, representing conditions when the soil surface water evaporation is minimal but root-zone soil moisture is adequate. The additional water evaporation from a wet soil condition after a rain or irrigation was estimated from models by Ritchie (1972) and Hanks (1974) and subtracted from measured ET data using lysimeters at two sites in Nebraska. These corn crop coefficient equations can be used with current irrigation scheduling programs for estimating daily ET values for corn, and should increase the accuracy of irrigation scheduling for corn hybrids with different maturities. The crop coefficient equations based on growth stage can be used initially until accurate values for total seasonal growing degree days can be determined for particular corn hybrids.

INTRODUCTION

Improved water management in irrigation requires an accurate scheduling of irrigations. The adoption of irrigation scheduling programs such as those described by Kincaid and Heermann (1974) has resulted in reduced application of water. These programs provide estimates of when and how much to irrigate by using daily weather data and other data related to the specific crop and soil conditions under consideration. Irrigation scheduling can reduce excessive irrigation, save energy, and use nutrients more efficiently.

A necessary requirement of an irrigation scheduling program is the accurate calculation of daily crop evapotranspiration (ET). Crop ET can be estimated using reference ET and a crop coefficient. The crop coefficient is the ratio of crop ET to some reference ET. Crop coefficient equations have generally been presented as a function of time, usually as a percentage of elapsed time from planting to full cover for the first part of the growing season, and days after full cover for the latter part of the growing season.

To provide a basis for directly relating the crop coefficient to crop development and to account for the changes from normal weather conditions, field experiments to develop improved crop coefficients were conducted at two sites in Nebraska. The crop coefficients presented in this paper are daily basal values, representing conditions when soil evaporation is minimal, but the availability of soil water within the root zone does not limit plant growth or transpiration. The results presented in this paper are summarized from a project completion report (Hinkle et al, 1984). The objective was to develop new crop coefficient equations that are a function of fraction of total growing degree days from emergence to maturity, and also as a function of growth stage.

METHODS AND MATERIALS

LOCATION, CLIMATE AND SOILS

The field experiments conducted to develop improved crop coefficients were performed at two different experimental sites. Site one was at the Sandhills Agricultural Laboratory (41°37' N latitude; 100°50' W longitude; 975 m above sea level) in McPherson Co. near Tyron, Nebraska. Site two was at the Rogers Memorial Farm in Lancaster Co. near Lincoln, Nebraska (40°49' N latitude; 96°42' W Longitude, 350 m above sea level). Both sites are research facilities of the University of Nebraska. Lysimetric measurements of crop evapotranspiration (ET) were made at the Sandhills Agricultural Laboratory during 1978, 1980 and 1981, and at the Rogers Memorial Farm during 1980 and 1981.

The Sandhills Ag. Lab. (SAL) site has a semiarid climate with an average annual rainfall of 53.6 cm (21.1 in). It is situated in the native grass covered rolling sandhills of west central Nebraska. Hot dry southerly winds, warm days, and cool nights are characteristic of its summer weather. Soils at the Sandhills Ag Lab are a coarse textured Valentine very fine sand to a loamy fine sand (Typic Ustipsament).

The Rogers Farm site has a subhumid climate with and average annual rainfall of 74.2 cm (29.2 in). It is situated in the rolling hills of southeastern Nebraska that developed from erosion of loess deposited plains. Occasional dry southerly winds, hot and humid days, and warm nights characterize the growing season. Soils at the Rogers Farm are fine textured Sharpsburg silty clay loam (Typic Argiudolls).

The corn hybrids in these experiments exhibited a wide range of maturity. The specific hybrids, their approximate maturity lengths for this region, the approximate average number of leaves developed by each hybrid, and the hybrid designation as used in this report are given in Table 1. Planting and emergence dates were unique for a particular location and year, and are summarized in Table 2.

GROWTH STAGE

Growth stage was measured one or two times per week. Growth stage was characterized by using the scale developed by Hanway (1971). The scale developed by Hanway (1971) implies the development of four fully emerged leaves per stage or twenty total leaves during the vegetative period. If a particular hybrid did not develop twenty total leaves, the following modification was made:

$$\text{Stages}_i = \frac{\text{No. of current fully emerged leaves}}{\text{Total no. of fully emerged leaves}} \times 5 \qquad (1)$$

where, i is the stage number, 1 through 5.

This modification was needed because the range of the total fully emerged leaves for the hybrids involved in this experiment was between 15 and 22 leaves.

LYSIMETERS

Hydraulic lysimeters similar to a design by Hanks and Shawcroft (1965) were used for ET measurement at both locations. The lysimeters had inside dimensions of 76.2 cm by 152.4 cm by 111.8 cm depth (30 in. by 60 in. by 44 in. depth). A two-liquid (mercury and an antifreeze-water solution) manometer system was used to balance the weight of the lysimeter box and measure ET. The lysimeters contained a vacuum drainage system to remove any gravitational water resulting from a large rainfall, and consisted of 1.27 cm (1/2 in) outside diameter, one bar ceramic tubes connected to a copper manifold, water collection containers, and a vacuum pump.

Rainfall was measured at a central weather station located near the lysimeters. Irrigation was measured by using four raingauges at each lysimeter, one placed near each corner. Rainfall and drainage amounts were measured at the same time that the lysimeter was read.

CALCULATED GROWING DEGREE DAYS

From a preliminary study (Hinkle et al, 1984), growing degree days (GDD) calculated by the 50-90 F (10-32 C) stress method was determined to be the best independent variable for predicting corn growth among different years and corn hybrids. Growth stage data from the Rogers Farm and for the Sandhills Ag. Lab. were used for up to five different years and with up to seven different corn hybrids. The 50-90 stress method is called a stress method because the upper limit is not just a limit for the maximum value of temperature, but actually further reduces it by the amount that measured maximum temperature exceeds the upper limit. The 50-90 stress method alters maximum temperature as follows:

$$T_{max} = T_{max} \text{ ; if } T_{max} \text{ is } \leq 90° \text{ F.} \qquad (2)$$

$$= 90 - (T_{max} - 90) \text{ ; if } T_{max} \text{ is } > 90° \text{ F.} \qquad (3)$$

Linear regressions of stage of growth versus the cumulative growth factors were made and standard errors of estimate and correlation coefficients were compared. Among all years and hybrids analyzed, the 50-90 stress method had the lowest overall standard error of estimate for predicting growth stage.

Other researchers also concluded that the 50-90 stress method of predicting corn growth was best (Cross and Zuber, 1972; Gilmore and Rogers, 1958). Lehenbauer (1914) and Coelho and Dale (1980) found corn grew very little or not at all below 10°C (50°F) and that the rate of growth increased almost linearly with increased temperature up to approximately 30 to 32°C (86 to 90°F). Above 32°C, the rate of growth decreased with increasing temperature. Mederski,et al. (1973) found all GDD methods to be superior to time as a predictor of corn growth, and they along with Coelho and Dale (1980) and Gilmore and Rogers (1958), all felt that temperature is the most important factor affecting the rate of corn growth.

BASAL CROP COEFFICIENTS

The crop coefficients (Kco) that are presented in this report are defined as the crop evapotranspiration (ET) divided by a reference ET. The modified Penman equation as presented by Kincaid and Heermann (1974) was used to calculate the reference ET values needed to determine Kco values. All of the Kco equations presented in this paper are basal equations, i.e., they predict the crop coefficient for normal, dry surface conditions. Two methods were used to determine the basal Kco equations. Method one simply deleted the ET data taken on the few days following a rain or an irrigation event. Method two involved correcting the measured ET values taken after a rain or irrigation to basal values.

Evapotranspiration values for the two to three days after a rain or irrigation at SAL during 1978 and 1980 were deleted from the data sets before the crop coefficient equations were calculated. Infrequent rainfall events and the coarse textured soils allowed the use of this method at SAL during the years of 1978 and 1980.

The second method was used on the 1981 ET data from SAL and all the data from the Rogers Farm because of more frequent rainfall events. The ET values from these data sets were changed to basal values by using an ET model (Ritchie, 1972) and a soil drying equation to estimate the additional soil evaporation taking place following a rain or irrigation and subtracting the result from the measured ET values.

The potential soil evaporation values below the crop canopy were used together with a soil drying equation by Hanks (1974) to determine dry soil surface evaporation rates:

$$E = Ep \quad \text{, stage 1 drying} \qquad (4)$$
$$= Ep(tp/t)^{0.5}\text{, stage 2 drying, } t \geq tp$$

where,
- E = soil evaporation rate, mm/day
- Ep = potential soil evaporation rate, mm/day
- tp = time of stage 1 drying, days
- t = time since a rain or irrigation, days

Hanks used a value of one day for the time of stage 1 drying and Ritchie used a maximum cumulative stage 1 evaporation value to determine the end of stage 1 drying. These values were found from drying experiments using lysimeters on a hybrid of different soils. However, the duration of stage 1 was generally between 1.0 and 1.5 days for the different soils. One day was assumed for the stage 1 drying time in these experiments.

The evaporation rate after six days in equation 4 was used as the basal, dry surface evaporation rate. Six days was judged a sufficient time for the soil surface to dry with or without a crop canopy for the silty clay loam soils at the Rogers Farm and more than sufficient time for the sandy soils at SAL. Integration of equation 4 for stage 2 drying and subtracting the basal evaporation rate gives an equation for the additional evaporation after a rain or irrigation:

$$Eadd = 0.59\ Ep\text{ ; stage 1, first day after rain or irrigation} \qquad (5)$$
$$= (2(t^{0.5} - (t-1)^{0.5}) - 0.41)Ep\text{, stage 2, for } t = 2 \text{ to } 6 \text{ days after a rain or irrigation}$$

where,
- $Eadd$ = additional daily evaporation after a rain or irrigation, mm/day
- Ep = potential soil evaporation below the crop canopy calculated using the technique from Ritchie (1972), mm/day
- t = days after a rain or irrigation.

Both linear and polynomial equations were used to describe the crop coefficients obtained from these experiments. The following equations are used throughout this paper to describe the results:

Linear model

initial horizontal segment

$$Kco = e; \ 0 \leq x \leq c \qquad (6)$$

increasing segment

$$Kco = a + bx; \ c < x < d \qquad (7)$$

peak horizontal segment

$$Kco = f; \ d \leq x \leq p \qquad (8)$$

decreasing segment

$$Kco = g + hx; \ p < x \leq q \qquad (9)$$

where, x is the independent variable (growth stage, or fraction of total growing degree days).
a,b,e,f,g,h are regression coefficients
c,d,p,q are independent variable boundaries

Polynomial model

initial horizontal segment

$$Kco = F; \ 0 \leq x \leq r \qquad (10)$$

remaining polynomial segment

$$Kco = A + Bx + Cx^2 + Dx^3 + Ex^4; \ \ r < x \leq s \qquad (11)$$

where, x is the independent variable. (growth stage, or fraction of total growing degree days).
A,B,C,D,E,F are regression coefficients
r and s are independent variable boundaries

CROP COEFFICIENT RESULTS AND DISCUSSION

Crop coefficient equations were first developed from 1980 Rogers Farm lysimeter ET data using the HYB120 hybrid (Hinkle, 1981). Different types of equations were investigated for use in predicting crop coefficients. Single equations were defined across the entire season, and split season equations were defined before effective full cover and after effective full cover. Hinkle (1981) concluded that: 1) because Hanway's (1971) stage of growth scale defines stage zero as emergence, any independent variable should be expressed from emergence and not from planting, and 2) any segmenting of the Kco equations should be done without splitting the season before and after some observed crop event so that the equations are more useful for crop modeling and for practical field use.

Attempting to split the season with two polynomials to obtain the best fit of equation(s) to the data points lead to numerous discontinuity problems. Straight line equations proved to be as effective or even better for defining the three periods (increasing, peak, decreasing) of the crop coefficient relationship. Expressing GDD as fraction of total GDD from emergence to maturity rather than total cumulative GDD from emergence presents the possibility of having one universal equation for all hybrids, regardless of maturity length.

Crop coefficient values and equations derived from the 1980 Rogers Farm data are shown in figure 1. The fourth order polynomial equation is shown along with linear equations for the increasing and decreasing Kco periods, all as a function of fraction of total cumulative 50-90 stress GDD. Coefficients for the linear and polynomial models are given in Table 3.

1981 ROGERS FARM

Predicting the crop coefficient using the dimensionless, fraction of total cumulative 50-90 stress GDD as the independent parameter was tested with different maturity lengths of corn at the Rogers Farm in 1981. Experiments were conducted using six different corn hybrids with nominal maturity lengths of 80, 85, 100, 105, 120, and 140 days. Polynomial Kco equations for the six hybrids as a function of cumulative 50-90 stress GDD are shown in figure 2. Differences in the number of GDD necessary to reach maturity are evident.

The peak ET values were 1.01, 1.08, 1.02, 1.07, 1.08, and 1.13, for the 80, 85, 100, 105, 120, and 140 day maturity corn hybrids, respectively. The overall average for the Rogers Farm in 1981 was 1.07 and the overall average for the Rogers Farm was 1.05 for both years (1980 and 1981).

Combining the linear crop coefficient equations for the Rogers Farm during 1981 shows good similarity among the six hybrids (figure 3). However, the one exception is HYB120 which has a larger slope and hence, predicts a value of 1.0 much sooner than the linear equations for the other hybrids and was due to that hybrid developing a larger LAI sooner than the other hybrids.

Overall linear and polynomial regression results for the Rogers Farm in 1981 are also given in Table 3. The overall linear regression for the increasing Kco data does not include HYB120 because of its dissimilarity from the other five hybrids. However, HYB120 is included in the overall Kco linear decreasing equation.

The fourth order polynomial is also shown in figure 3. The polynomial equation peaks at 1.14 while the overall average is 1.07 for the peak period data points. The polynomial equation underpredicts the time when the crop coefficient value should reach a value of one. This again tends to show that the linear equations better represent the crop coefficient relationship.

OVERALL ROGERS FARM

The overall 1981 Rogers Farm crop coefficient equations are plotted in figure 4 along with the 1980 Rogers Farm equations, and are similar. However, the 1980 increasing linear equation predicts Kco values up to 0.15 larger near the beginning of the season than the same equation for 1981. The main differences in the polynomial equations occurs during the middle of the season, due to the differences in the average value of the peak period between the two years. Linear and polynomial regression results for the Rogers Farm for both years are also given in Table 3.

SANDHILLS AG. LAB.

In order to further test the nondimensional fraction of total cumulative GDD parameter, an analysis was done on lysimetric measured ET data from SAL for three years (Kranz, 1981). Crop coefficient values and equations were determined from SAL data for HYB105, HYB110, and HYB120, in 1981, HYB120 in 1980, and HYB100 in 1978. Linear and polynominal Kco equations for SAL are plotted in figure 5. Early season data points in 1978 and 1980 were missing, so increasing linear and polynomial equations were not determined for those years.

The regression results of Kco versus fraction of total cumulative 50-90 stress GDD for the three hybrids during 1981 are given in Table 4. The peak Kco values at SAL for 1978 and 1980 were generally lower and more variable than the 1981 Rogers Farm results. The overall average peak Kco value was 0.98 for 1980-81 at SAL and was 0.99 for all three years at SAL. Overall crop coefficient equations from SAL are also plotted in figure 5.

COMBINED SAL & ROGERS FARM RESULTS

A graphical comparison of the crop coefficient results from both SAL and Rogers Farm is shown in figure 6 and shows good similarity during the Kco increasing time period. However, a difference exists in the decreasing linear Kco equation between locations. Regression coefficients for the combined Kco equations are in Table 5.

The peak value of the fourth order polynomial is 1.10 and the overall average of the peak Kco values is 1.02 for all years and both locations. Again, the polynomial overpredicts at the peak period and underpredicts where the linear equations intersect. Integration of the polynomial model over the season equals 0.714 and integration of the linear equations equal 0.716.

The difference in the crop coefficients developed at the Rogers Farm and SAL can be partially explained by the following analysis. Time, GDD, LAI, and stage of growth data for the times that Kco reaches and declines from a value of one at both locations are tabulated in Table 6. These times were determined from the respective linear increasing and decreasing Kco equations for each hybrid at each location. Apparently, if shorter season hybrids are planted in a region with a relatively long growing season, the peak Kco period tends to start and end at LAI values more closer to a threshold 2.7 value. The peak period also appears to be more closely associated with stage of growth, especially at the time that peak Kco period ends. The four hybrids with the shortest maturity lengths at the Rogers Farm begin the peak Kco period near an average stage of growth value of 4.2 (tassel emergence). This particular growth stage may not be significant due to the modification of Hanways vegetative scale to accommodate hybrids with different total leaf numbers. However, these same four hybrids all end their peak Kco periods near stage 9.1, just after full kernel dent.

The shortest season hybrid (HYB105) grown at SAL appears to have these same characteristics with LAI value of 2.8 and 2.9, at the beginning and end of its Kco period. However, this was because its peak LAI was never much greater than these values and not because of the short maturity effects exhibited at the Rogers Farm. HYB105 ends its Kco peak period at stage 7.8, much sooner than the 9.1 average value at the Rogers Farm, where season length was not limited by cooler nights or earlier frost events.

All three hybrids at SAL ended their Kco peak periods when minimum temperatures dropped below 40°F (4.4°C). Stage of growth at this time for the three hybrids ranged form 7.2 to 7.9, medium to hard dough, and was sooner than even the later maturity hybrids at the Rogers Farm ended their Kco peak periods. The three hybrids at SAL, however, maintained their peak leaf area for two or more weeks, and did not start to decline significantly until after the first frost. These temperature effects seem to have had no bearing on the results at the Rogers Farm because leaf area started to decline long before minimum temperatures dropped below 40°F. Since the hybrids at SAL end their peak Kco periods much sooner, their equations have a larger intercept but yet have a similar slope, as is shown in figure 6. This difference my be almost entirely due to the relative maturity effects as just discussed.

OVERALL RESULTS COMPARED TO THE JENSEN EQUATIONS

Crop coefficient equations have been developed for a number of different crops by Jensen (1969), Jensen et al. (1970), and Jensen et al. (1971). These equations were found from data taken at a number of locations in semiarid regions and are presented by Kincaid and Heermann (1974). The overall linear Kco equation for the Rogers Farm for the different hybrids are compared to the corn crop coefficient equations developed by Jensen and others in figure 7. The crop coefficient and leaf area results show there is little difference between hybrids for the time period before effective full cover. However, there was a difference in the duration of the peak Kco period. Therefore, one equation was found for all hybrids for the time period before effective full cover. However, due to the difference in duration of the Kco peak period, equations were developed for each hybrid for the period after effective full cover.

The value of fraction of total seasonal GDD of the overall Kco increasing equation with a Kco value of 1.0 was used to find the GDD at effective full cover for each hybrid. These GDD values ranged from 962 to 1206 with an average of 1082 which occurred on calendar day 191 or July 10th. All hybrids were planted on calendar day 127 or May 7th. From these results, time values were found for every tenth increment of increasing Kco and are shown in figure 7.

The values predicted by the overall linear crop coefficient equation before effective cover are significantly lower than those values predicted by the Jensen equation. However, values presented by Wright (1982) are more similar to those values obtained at the Rogers Farm. The revised values found by Wright are from lysimeter measurements and incorporate improved techniques for finding basal, dry soil surface, ET values.

The six hybrids grown at the Rogers Farm during 1981 are represented by different lines for the period of days after effective full cover due to differences in the duration of the peak Kco period. Both early season hybrids at the Rogers Farm during 1981 matured at the same time, so both are represented by the same line.

The two short season hybrids compare fairly well with the Jensen equation for the period after effective full cover. However, there is significant dissimilarity between the two lines where Kco begins to decrease. Much of this dissimilarity can be expected due to the problem with using polynomials to represent the Kco data.

The other hybrids, HYB100, HYB105, HYB120 and HYB140, all have progressively longer peak Kco periods and subsequently, different Kco decreasing lines become less linear and more parallel to Jensen's equation with increased maturity length.

Relative maturity length within a region seems to have an effect on the shape of the Kco decreasing line when represented by time. The long maturity hybrids at the Rogers Farm have non-linear Kco decreasing lines because the cooler fall weather required more time to acquire the later GDD to bring about senescence. This was not true with the two shorter season hybrids, which both matured August 31st, long before temperature became a factor to effect senescence. The Jensen equation after effective full cover appears to represent a short season hybrid because of its short peak Kco period but yet a hybrid that is relatively late-maturing for the region it was grown as depicted by the shape of the Kco decreasing line.

CROP COEFFICIENT EQUATIONS BASED ON GROWTH STAGE

Using linear relationships between growth stage and GDD from Hinkle et al (1984), corn crop coefficient equations were developed as a function of growth stage and are shown in figure 8. Regression coefficients for the growth stage equations are given in Table 7. The equations of Kco as a function of growth stage were developed as a practical method for on-farm use since growth stage can be readily observed. The total GDD values provided by seed corn companies for their hybrids may not be accurate for every particular location due to differences in latitude and elevation. The Kco versus growth stage equations can be used until more accurate values of total GDD can be determined for each hybrid.

SUMMARY

New crop coefficients were developed for use in calculating corn evapotranspiration at a given growth stage or fraction of total cumulative growing degree days. Growing degree days were calculated by a 50-90 F stress method. Growth stage parameters were those developed and defined by Hanway (1971). The coefficients are basal or minimal coefficients, representing conditions when the soil surface water evaporation is minimal but root-zone soil moisture is adequate. The additional water evaporation from a wet soil condition after a rain or irrigation was determined from models by Ritchie (1972), and Hanks (1974). These new crop coefficient equations can be used with current irrigation scheduling programs for estimating daily ET values for corn, and should increase the accuracy of irrigation scheduling for corn hybrids with different maturities. The crop coefficient equations based on growth stage can be used initially until accurate values for total seasonal growing degree days can be determined for particular corn hybrids.

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Table 1. Corn hybrids grown at the Rogers Memorial Farm and the Sandhills Ag. Lab during the study period.

Hybrid	Approximate Maturity Length, days	Average No. of Total Leaves	Hybrid Designation
Dekalb DK24	80	15.4	HYB80
Dekalb XL6	85	16.7	HYB85
Pioneer 3901	100	18.5	HYB100
Pioneer 3780	101	19.0	HYB101
A619 x A632	105	19.4	HYB105
MO17 x A634	110	20.0	HYB110
MO17 x B73	120	20.4	HYB120
Dekalb XL395	140	22.0	HYB140

Table 2. Planting dates and emergence dates for each location and year for the corn experiments.

Location-year	Planting Date	Emergence Date
SAL78	May 19, 1978	May 27, 1978
SAL80	May 7, 1980	May 20, 1980
SAL81	May 22, 1981	May 31, 1981
ROG80	May 7, 1980	May 20, 1980
ROG81	May 7, 1981	May 22, 1981

Table 3. Regression coefficients for the corn crop coefficients from the Rogers Farm

Linear Model

Year	Hybrid	initial constant segment Kco = e; $0 \leq x \leq c$ e	c	increasing linear segment Kco = a + bx; $c < x < d$ a	b	d	Corr. Coef.
1980	All	0.15	0.10	-0.088	2.532	0.43	0.81
1981	All except HYB120	0.15	0.15	-0.290	3.014	0.45	0.81
Both	All except HYB120	0.15	0.12	-0.183	2.724	0.45	0.79

Year	Hybrid	peak constant segment Kco = f; $d \leq x \leq p$ f	p	decreasing linear segment Kco = g + hx; $p < x \leq 1.0$ g	h	Corr. Coef.
1980	All	1.00	0.85	3.444	-2.880	0.71
1981	All	1.07	0.81	3.570	-3.094	0.58
Both	All	1.05	0.82	3.459	-2.955	0.58

Polynomial model initial constant segment, Kco = F; $0 \leq x \leq r$

Year	Hybrid	F	r
1980	All	0.15	0.09
1981	All except HYB120	0.15	0.12
Both	All except HYB120	0.15	0.11

remaining polynomial segment, $Kco = A + Bx + Cx^2 + Dx^3 + Ex^4$; $r < x \leq 1.0$

Year	Hybrid	A	B	C	D	E	Corr. Coef.
1980	All	-0.0469	2.133	1.819	-4.745	1.465	0.82
1981	All except HYB120	0.0265	-0.0435	11.195	-17.422	6.716	0.78
Both	All except HYB120	0.0240	0.262	9.931	-16.079	6.406	0.78

Note: Independent variable is fraction of total cumulative 50-90 F stress GDD. Linear model is described by equations 6 to 9, polynomial model is described by equations 10 to 11.

Table 4. Regression coefficients for the corn crop coefficients from SAL

Linear Model

Year	Hybrid	initial constant segment Kco = e; $0 \le x \le c$ e	 c	increasing linear segment Kco = a + bx; $c < x < d$ a	 b	 d	 Corr. Coef.
1981	HYB105	0.15	0.13	-0.2036	2.719	0.43	0.783
	HYB110	0.15	0.11	-0.1870	3.000	0.43	0.798
	HYB120	0.15	0.11	-0.1648	2.859	0.39	0.672
1981	All	0.15	0.12	-0.2043	2.948	0.40	0.763

Year	Hybrid	peak constant segment Kco = f; $d \le x \le p$ f	 p	decreasing linear segment Kco = g + hx; $p < x \le 1.0$ g	 h	 Corr. Coef.
1980	HYB100	1.04	0.72	2.867	-2.534	0.689
	HYB120	0.96	0.77	3.020	-2.676	0.689
1981	HYB105	0.96	0.78	3.371	-3.091	0.742
	HYB110	1.09	0.78	3.424	-3.009	0.728
	HYB120	0.94	0.77	3.720	-3.595	0.513
Both	All	0.99	0.76	3.090	-2.767	0.553

Polynomial model initial constant segment, Kco = F; $0 \le x \le r$

Year	Hybrid	F	r
1981	HYB105	0.15	0.10
	HYB110	0.15	0.13
	HYB120	0.15	0.06
1981	All	0.15	0.10

remaining polynomial segment, $Kco = A + Bx + Cx^2 + Dx^3 + Ex^4$; $r < x \le 1.0$

Year	Hybrid	A	B	C	D	E	Corr. Coef.
1981	HYB105	0.1664	-1.776	18.763	-30.729	14.106	0.664
	HYB110	-0.5416	6.357	-9.084	7.577	-3.947	0.701
	HYB120	0.1269	-0.271	11.987	-20.037	8.401	0.566
1981	All	0.0860	-0.438	14.162	-24.569	11.264	0.584

Note: Independent variable is fraction of total cumulative 50-90 F stress GDD. Linear model is described by equations 6 to 9, polynomial model is described by equations 10 to 11.

Table 5. Regression coefficients for the corn crop coefficients combined for both sites, all years and all hybrids.

Linear Model

Year	Hybrid	initial constant segment Kco = e; $0 \le x \le c$ e	c	increasing linear segment Kco = a + bx; $c < x < d$ a	b	d	Corr. Coef.
All	All	0.15	0.12	-0.180	2.738	0.44	0.767

Year	Hybrid	peak constant segment Kco = f; $d \le x \le p$ f	p	decreasing linear segment Kco = g + hx; $p < x \le 1.0$ g	h	Corr. Coef.
All	All	1.02	0.81	3.208	-2.698	0.525

Polynomial model initial constant segment, Kco = F; $0 \le x \le r$

Year	Hybrid	F	r
All	All	0.15	0.10

remaining polynomial segment, $Kco = A + Bx + Cx^2 + Dx^3 + Ex^4$; $r < x \le 1.0$

Year	Hybrid	A	B	C	D	E	Corr. Coef.
All	All	0.0447	-0.0349	11.592	-19.210	8.126	0.710

Note: Independent variable is fraction of total cumulative 50-90 F stress GDD. Linear model is described by equations 6 to 9, polynomial model is described by equations 10 to 11.

Table 6. Values of corn growth parameters for both locations during 1981 at the beginning and end of the Kco peak period.

Nominal Maturity Length	Calendar Day	Cumulative 50-90 F Stress GDD	Fraction of Seasonal GDD	Leaf Area Index		Stage of Growth	
Kco reaches a value of 1.0 at the Rogers Farm							
80	187	991	0.444	2.2		4.7	
85	186	967	0.433	2.9	Ave.	3.8	Ave.
100	190	1063	0.434	2.6	2.7	4.2	4.2
105	191	1105	0.425	3.0		4.2	
120	187	980	0.356	3.1		3.0	
140	193	1152	0.412	3.6		3.3	
Average	190	1056	0.431				
Kco reaches a value of 1.0 at SAL							
105	201	967	0.443	2.8		4.4	
110	198	885	0.396	3.3		3.9	
120	201	962	0.407	3.7		3.7	
Kco reaches a value of 1.0 at the Rogers Farm							
80	223	1836	0.822	2.4		9.1	
85	227	1934	0.866	2.8	Ave.	9.1	Ave.
100	228	1960	0.800	2.7	2.8	8.8	9.1
105	240	2158	0.830	3.3		9.3	
120	249	2325	0.845	3.6		8.5	
140	249	2331	0.833	4.7		8.1	
Kco reaches a value of 1.0 at SAL							
105	242	1708	0.764	2.9		7.8	
110	245	1760	0.806	3.5		7.9	
120	247	1787	0.756	4.0		7.2	

Table 7. Regression coefficients for the corn crop coefficients vs. growth stage equations for all sites and all years.

Linear Model

		initial constant segment Kco = e; $0 \le x \le c$		increasing linear segment Kco = a + bx; $c < x < d$			
Year	Site	e	c	a	b	d	Corr. Coef.
All	Rogers F.	0.15	0.66	-0.007	0.238	4.43	0.770
All	SAL	0.15	0.99	-0.139	0.295	3.83	0.756
All	All	0.15	0.69	-0.016	0.243	4.27	0.740

		peak constant segment Kco = f; $d \le x \le p$		decreasing linear segment Kco = g + hx; $p < x \le 10.0$		
Year	Hybrid	f	p	g	h	Corr. Coef.
All	Rogers F.	1.05	8.29	3.060	-0.243	0.587
All	SAL	0.99	7.44	2.920	-0.259	0.561
All	All	1.02	8.17	2.740	-0.211	0.500

Polynomial model initial constant segment, Kco = F; $0 \le x \le r$

Year	Hybrid	F	r
All	Rogers F.	0.15	0.60
All	SAL	0.15	0.60
All	All	0.15	0.60

remaining polynomial segment, $Kco = A + Bx + Cx^2 + Dx^3 + Ex^4$; $r < x \le 10.0$

Year	Hybrid	A	B	C	D	E	Corr. Coef.
All	Rogers F.	0.0605	0.1507	0.0409	-0.0079	0.00029	0.779
All	SAL	0.0340	0.0994	0.0936	-0.0192	0.00093	0.572
All	All	0.0805	0.0810	0.0806	-0.0150	0.00066	0.689

Note: Independent variable is Hanways (1971) corn growth stage. Linear model is described by equations 6 to 9, polynomial model is described by equations 10 to 11.

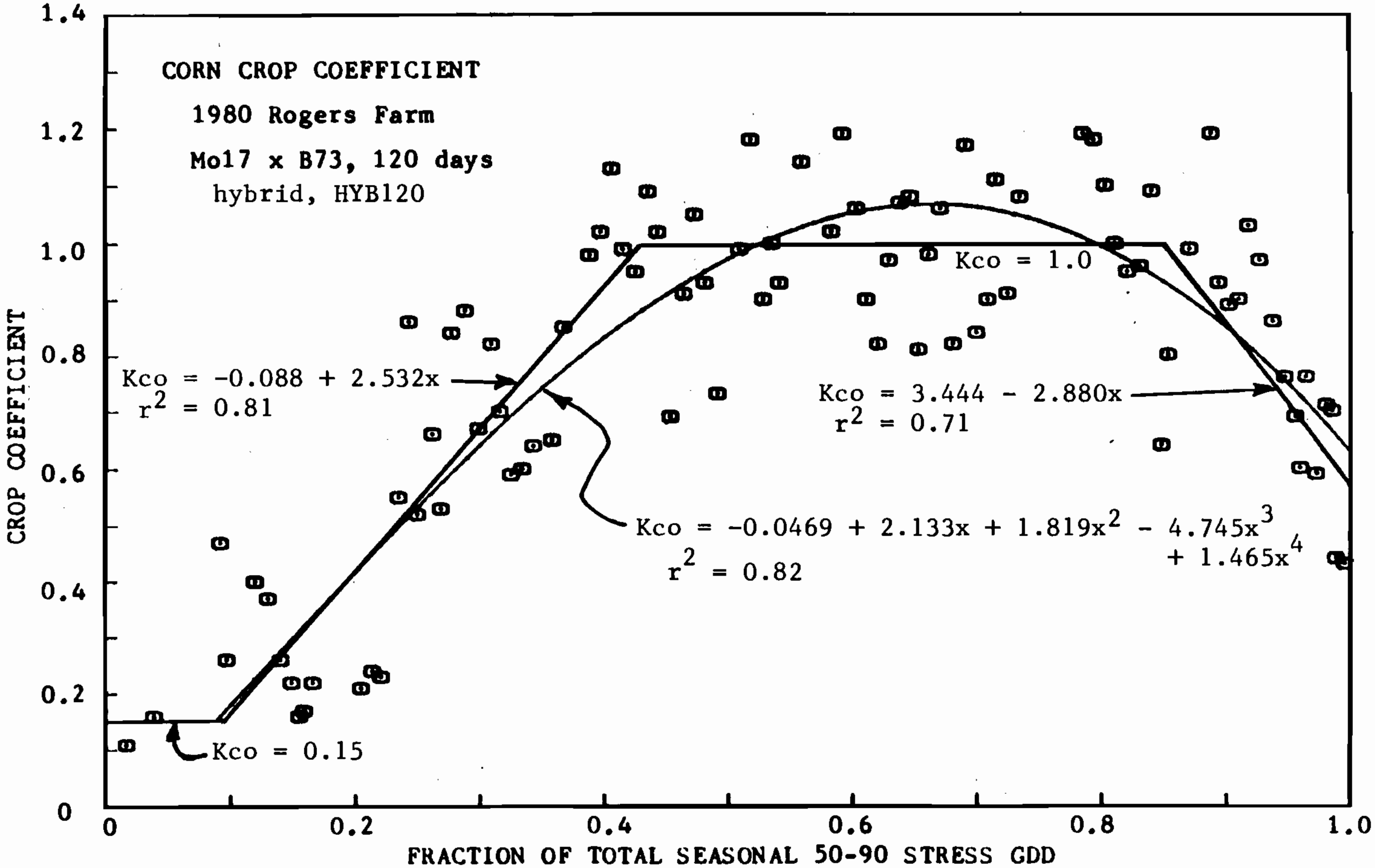

Figure 1. Corn crop coefficient results for HYB120 at the Rogers Farm during 1980.

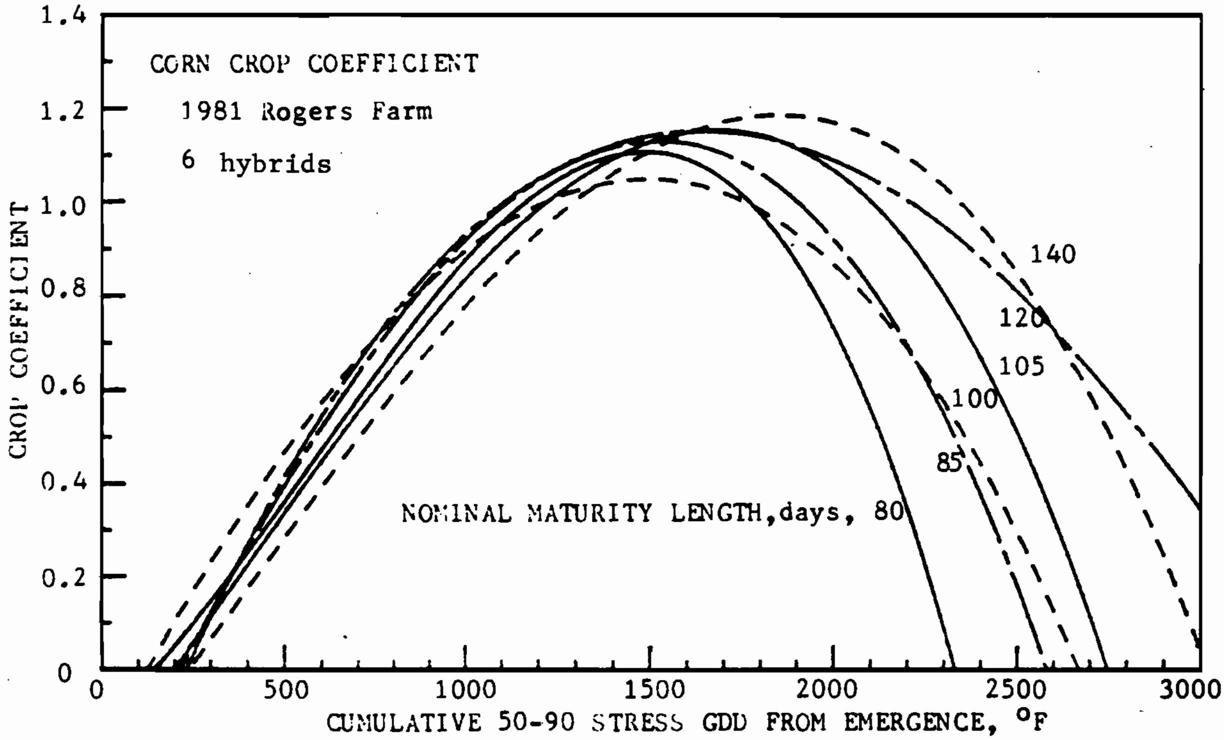

Figure 2. Corn crop coefficient values as a function of GDD for six hybrids at the Rogers Farm during 1981.

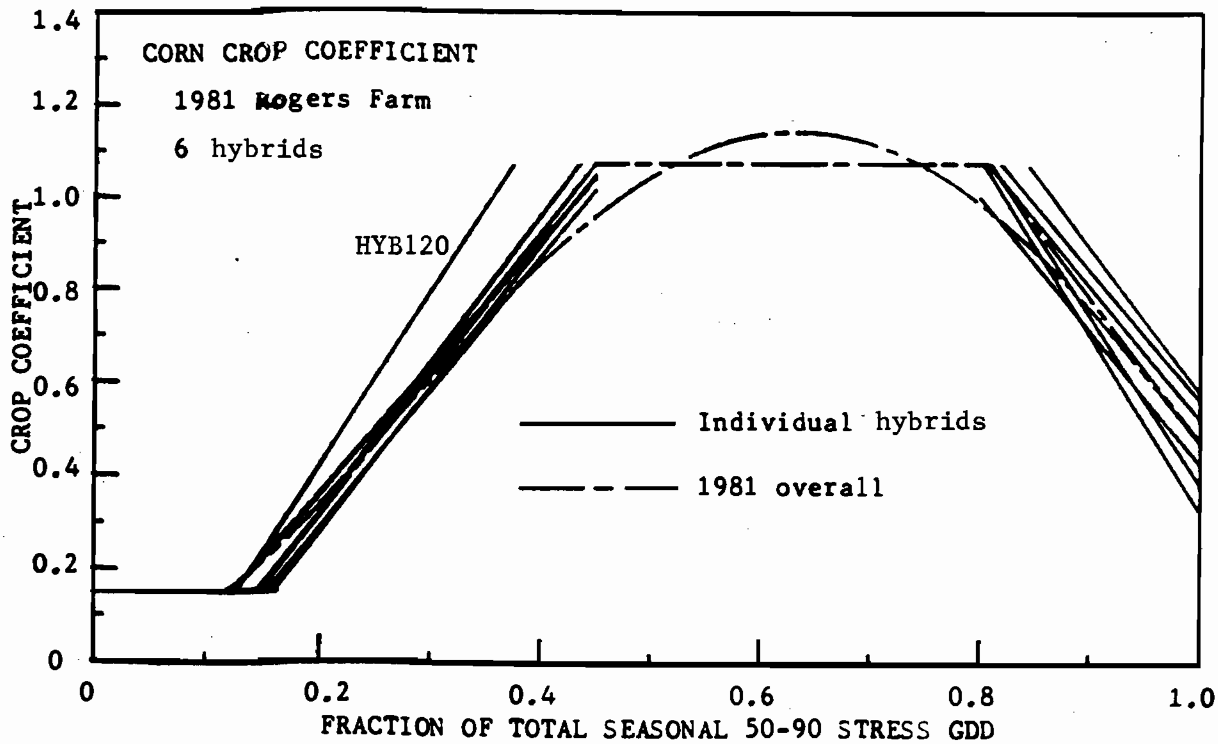

Figure 3. Overall corn crop coefficient values for six different maturity hybrids at the Rogers Farm during 1981.

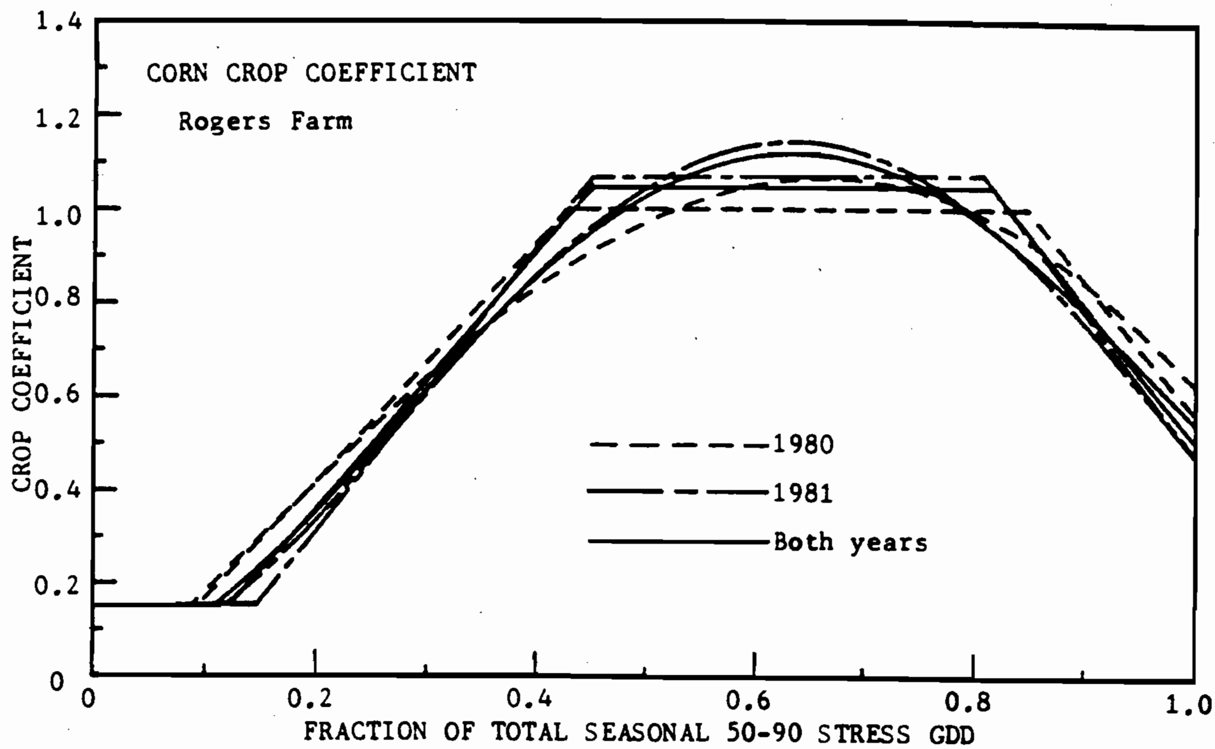

Figure 4. Overall corn crop coefficient values for the Rogers Farm for 1980 and 1981.

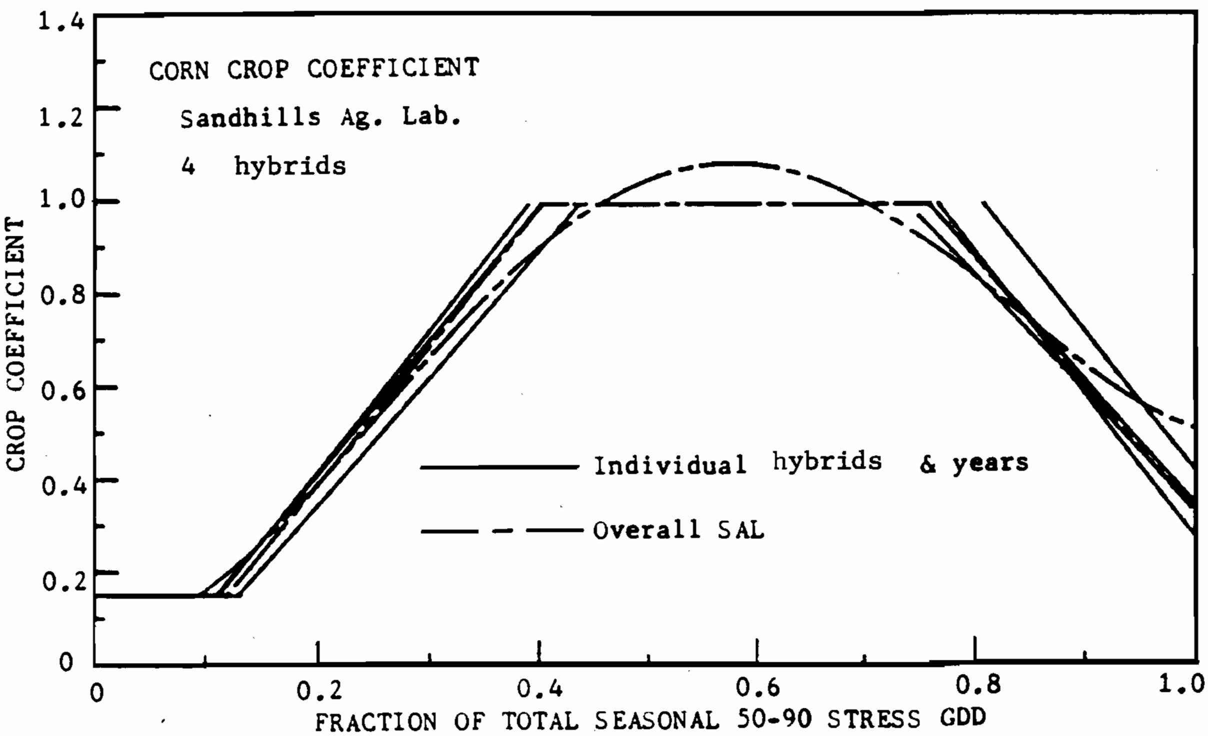

Figure 5. Overall corn crop coefficient values for the Sandhills Ag. Lab.

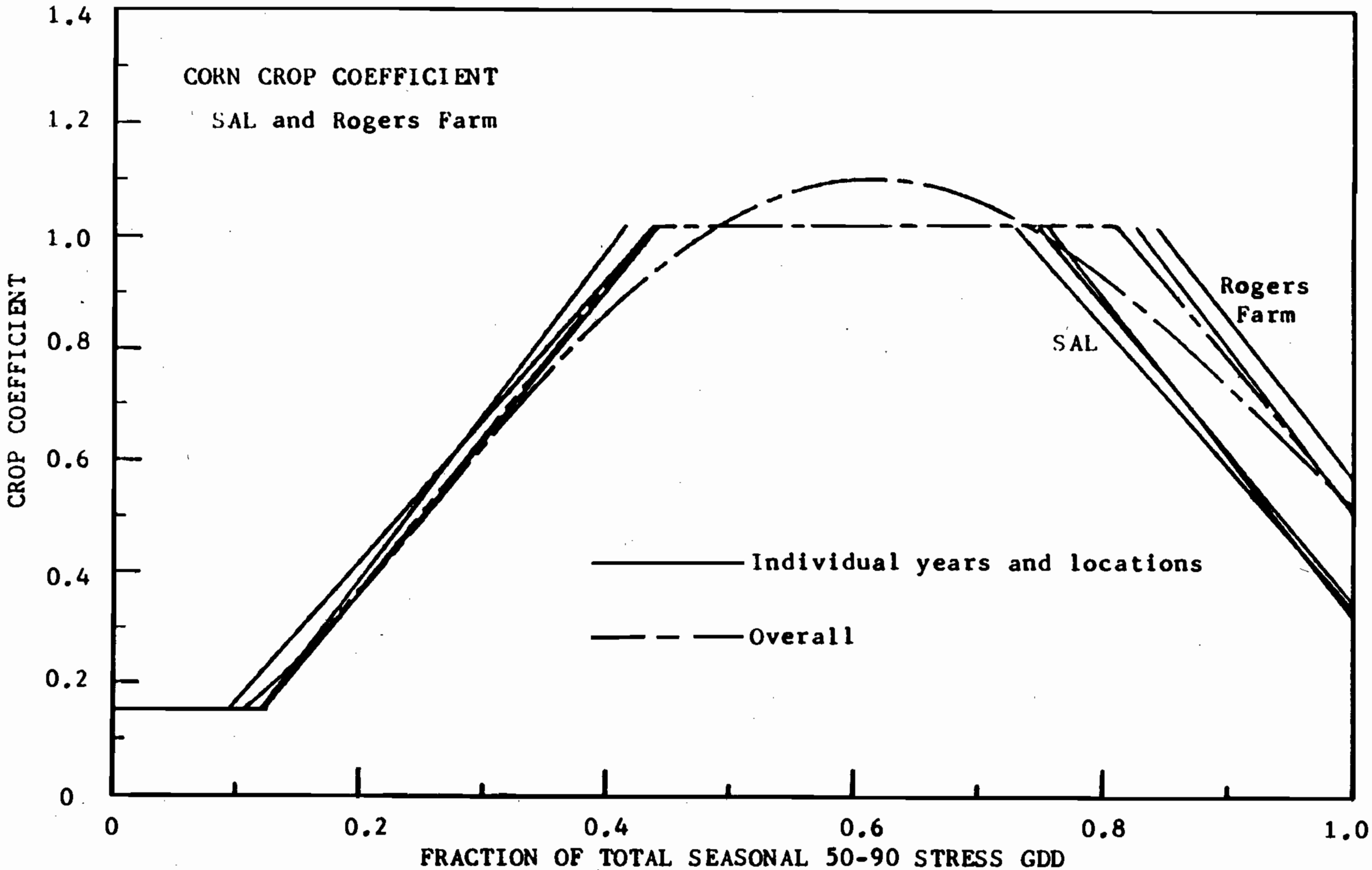

Figure 6. Overall corn crop coefficient values for the Rogers Farm and the Sandhills Ag. Lab.

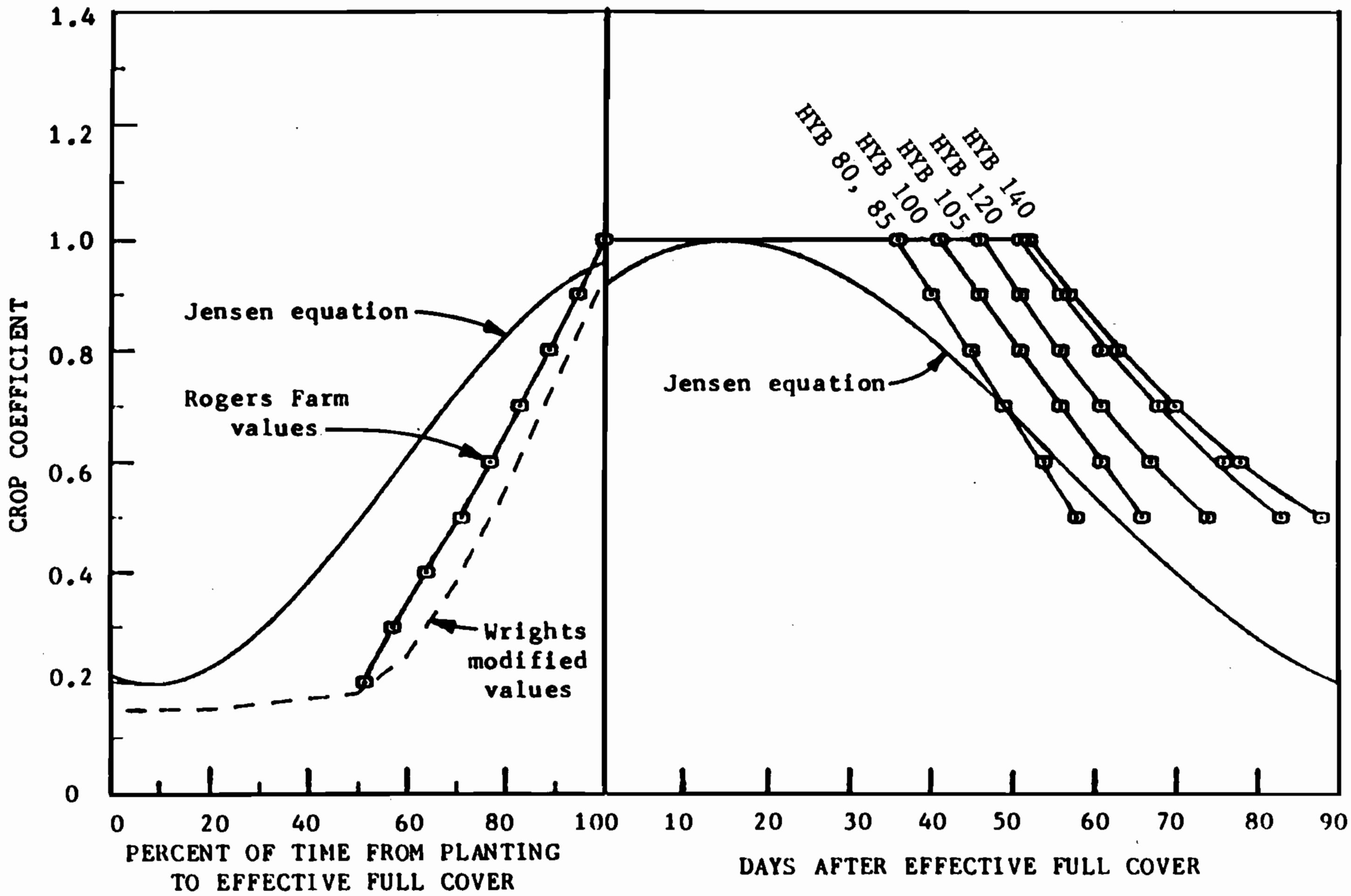

Figure 7. Comparison of the Rogers Farm crop coefficient results to Jensens equations for corn and Wrights (1982) modified values.

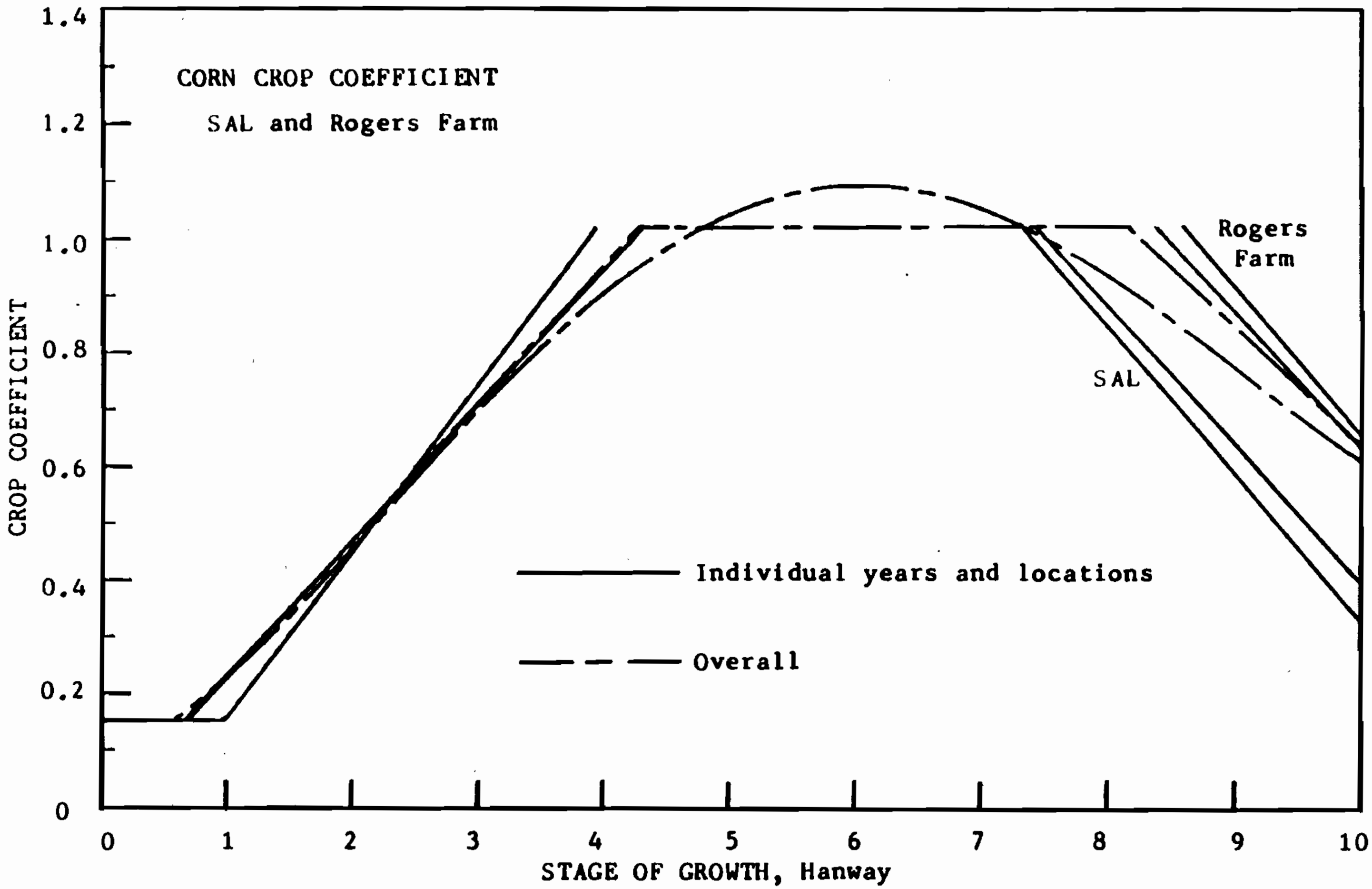

Figure 8. Overall corn crop coefficient values as a function of stage of growth for the Rogers Farm and the Sandhills Ag. Lab.