Procedure to easily Fine-Tune Crop Coefficients for Irrigation Scheduling

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Abstract. *A procedure is presented that allows crop coefficient values, as described in FAO-56, to be easily adjusted to meet local conditions. Values are adjusted vertically based on FAO-56 procedures and internal weather databases.*

*The paper calculates the season length of corn and soybeans based on Relative Maturity and Maturity Group, respectively. Within the determined growing season, the period of time for the four growth periods was determined by empirical equations relating length in days to air temperature. This is a logical procedure, as common sense dictates that the **initial period** would be longer when planting is done when the weather was cool, as opposed to when it was warm.*

*The paper shows how available national weather databases can be used to calculate **K-c _ini**, which can be difficult to calculate due to the background information required.*

Keywords. Crop coefficients, irrigation scheduling, FAO-56.

Introduction

This paper is based primarily on procedures to adjust crop coefficient (K_c) values as described in *FAO-56, Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56* (Allen et al., 1998). Adjustment procedures of K_c values allow one to take default K_c values as suggested in FAO-56 and make them more accurate for local conditions. Crop coefficient values are used in the following way to predict water use:

$$ET_c = ET_o \times K_c \qquad \text{Eq. 1}$$

Where, ET_c is the water use of the crop in question (mm or inches)

ET_o is reference evapotranspiration (mm or inches)

FAO-56 is actually very Spartan in concept, only dealing with three K_c values to describe conditions of the entire growing season; these points are: Kc_ini, Kc-mid, and Kc-end. Based on local climate conditions, these values can be increased or decreased, and is referred to as *vertical adjustment*.

The horizontal location of these three cardinal values is based on the number of days in each of the four crop stages (initial, development, mid-season, and end) for the crop in question. For each of the many crops discussed in FAO-56, there are generally four or five examples provided from around the world showing the length of time (i.e., the number of days) in each period. Adjusting the length of any of the periods, initiates *horizontal adjustment*. Through the three points which lay out horizontally based on values for the growing periods, a curve is constructed encompassing the whole growing season and is known as the *crop coefficient curve* (figure 1).

In the authors' opinions, FAO-56's weakest component regarding crop coefficients has been the lack of procedures to better determine Growth Period lengths. This paper attempts to provide a methodology to better determine growth period lengths using local weather information and other factors.

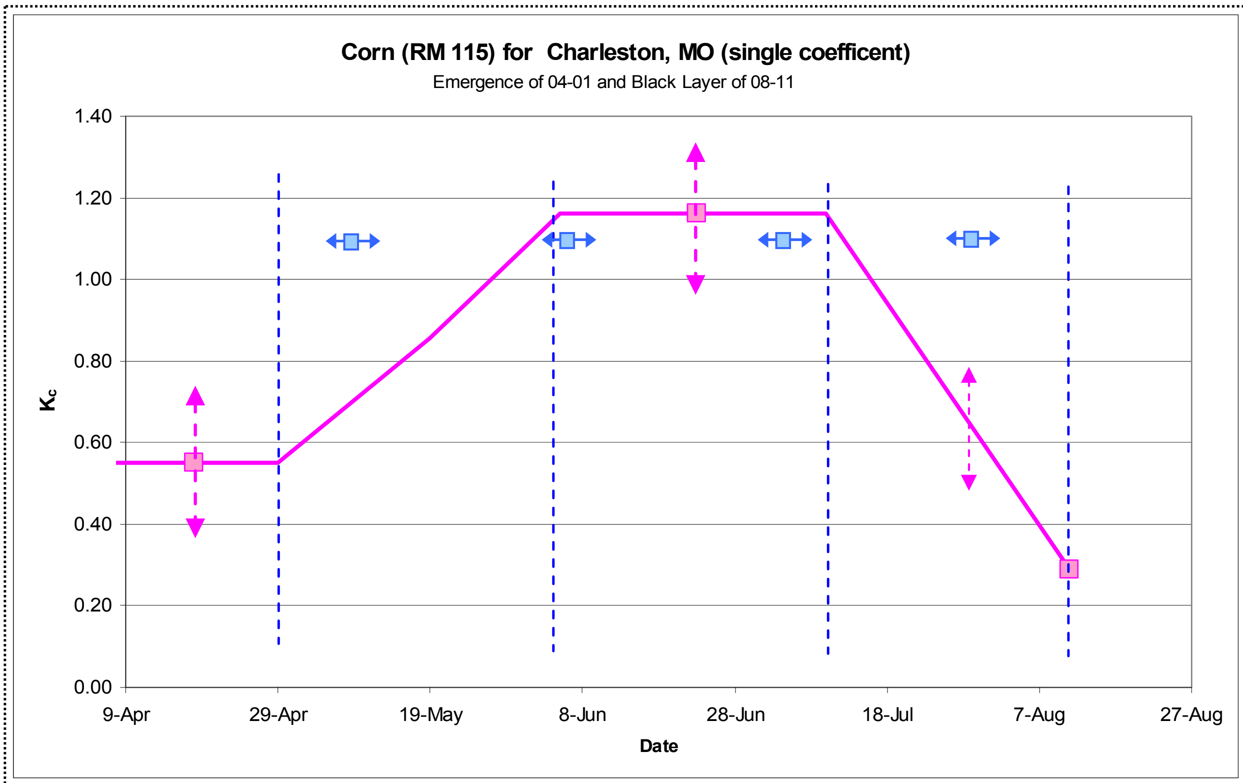

Fig. 1. A seasonal crop coefficient curve developed for corn in SE Missouri, showing the three cardinal K_c values in pink which can be vertically adjusted. Adjusting the lengths of time for each of the four periods (separated by the blue dashed lines) provides horizontal adjustment.

VERTICAL ADJUSTMENT – Coefficient Values

Crop coefficients are of two types. The most commonly used are the *single crop coefficient* (K_c). This one is used when crop transpiration (T) and soil evaporation (E) are combined jointly. The *dual crop coefficient* (K_{cb} +K_e) is used when T and E are calculated separately. The single crop coefficient value will be higher since it has to account for water loss through both T and E. Also, the amount of rainfall events is significant early in the season before canopies close.

Suggested values for both types of coefficients are provided in FAO-56. These values were derived from locations having an average daily minimum Relative Humidity value of 45% and an average daily wind speed of 2 m/s. Locales with different weather parameters can have their coefficient values adjusted using a simple equation (Allen, et al., 1998). Table 1 shows the factors used for adjustment for the three cardinal coefficient values of both types of coefficients.

Table 1. Factors used in adjusting crop coefficient values.

Type of coefficient	Period Coefficient		
	Kc_–ini	Kc_mid	Kc-end
Single crop coefficient (K_c)	~ ETo ~ frequency of wetting ~ wetting depth ~ soil type	~ crop height ~ min. RH ~ wind	~ crop height ~ min. RH ~ wind ~ desired harvest conditions
Dual crop coefficient (K_{cb})	No adjustment	~ crop height ~ min. RH ~ wind	~ crop height ~ min. RH ~ wind ~ desired harvest conditions

The most difficult data to collect needed to modifying crop coefficient values are those data needed for the Kc_ini value of the Single crop coefficient. However, the U.S. Department of Commerce has on line a database of about 300 cities in the US and its possessions that shows the data required to calculate the adjustment (U.S. Department of Commerce, 2008). Data on the number of rainfall events > 0.01 inch per month is used in the equation. Since rainfall on adjacent days is only counted as a single event, it is important to reduce the number or the Kc_ini value will be too high. A factor of 0.5 works well in Missouri. Figure 2 shows a print out of Kc values.

	Kc values from literature	Kc values Modified by local weather	Kc values being Used
Kc-ini [beg]	0.30	see Table 1 below	0.73
Kc-ini [end]			0.84
Kc-mid	1.20	1.15	1.17
Kc-end	0.35	0.35	0.50

Table 1. Kcini values

Sand	0.58
Loamy sand	0.59
Sandy loam	0.64
Loam	0.66
Silt loam	0.67
Silt	0.68
Silt clay loam	0.66
Silty clay	0.67
Clay	0.67

Fig. 2. Crop coefficient values modified with data in NOAA databases.

HORIZONTAL ADJUSTMENT – Lengths of the Growing Periods

FAO-56 provides helpful information on growth period length. An example, compiled from FAO-56 data on soybeans is shown in Figure 3. It has four locations and the differences in season length vary from 85 days to 135 days. This could be problematic for someone trying to construct a Kc curve for his own locale. One benefit of the data, however, is that the length of the Growth Periods can be seen as a percentage of the whole season. Once the expected season length is determined, for your locale then these percentages – converted to number of days- will be a good starting point.

Background on: Determining the length for the 4 growth periods							
Literature Review (from FAO-56) on Length for Various Periods							
	Initial	Development	Mid-Season	Late-Season	Total	Plant Date	Region
Lit Result 1	15	15	40	15	85	Dec	Tropics
Lit Result 2	20	35	60	25	140	May	Cent USA 1
Lit Result 3	20	30	60	25	135	May	Cent USA 2
Lit Result 4	20	25	75	30	150	June	Japan
Lit Result 5							
Lit Result 6							
Lit Average (days):	**19**	**26**	**59**	**24**	**128**		
Lit Average (% of days):	**15%**	**21%**	**46%**	**19%**			

Fig. 3. Typical growth period length data as reported in FAO-56.

Calculating Season Length

CORN. The termination date of corn can readily be predicted. The corn HU growth model (86◦F / 50◦F) that is universally used was developed at Texas A&M University in the 1950s (Gilmore and Rogers, 1958). Seed companies have made use of it for many years to predict both silking (very important for breeders) and black layer (important in quantifying the growing period required) in their hybrids, so its accuracy has been well established. However, seed companies use another scale to actually categorize hybrid season length, Relative Maturity (RM). RM is the estimated length in days of a hybrid's season. Farmers in a location may commonly have a 10-day span in the hybrids they are using. For example, in southeast Missouri (SEMO) the normal range in hybrids is RM 109 to RM 119. This in itself represents about a 10% error for irrigation programs that deal with corn generically. On top of this, RM values are only approximations based on "average" planting dates for that region, outside of this planting window and local weather patterns, the RM values loose accuracy. For example, in SEMO a hybrid with a RM value of 113 could have a season length ranging from 76 to 124 days depending if it emerged 1 Apr or 1 Jun.

Seed companies normally provide data on HUs to black layer (HU_{bl}). In cases where it is not known, the RM value can be used to predict HU_{bl} as seen in Equation 3.

$$HU_{bl} = -(0.0063 \times RM^3) + (2.20742 \times RM^2) - (204.17 \times RM) + 8407.5 \qquad \text{(Eq. 3)}$$

If where

HU_{bl} = ∑ HUs (86ºF limit on max. temperature and 50ºF-base) to black layer [ºF]

RM = seed company rating system for hybrid season length [days]

Figure 4 shows the relationship of RM to Heat Units.

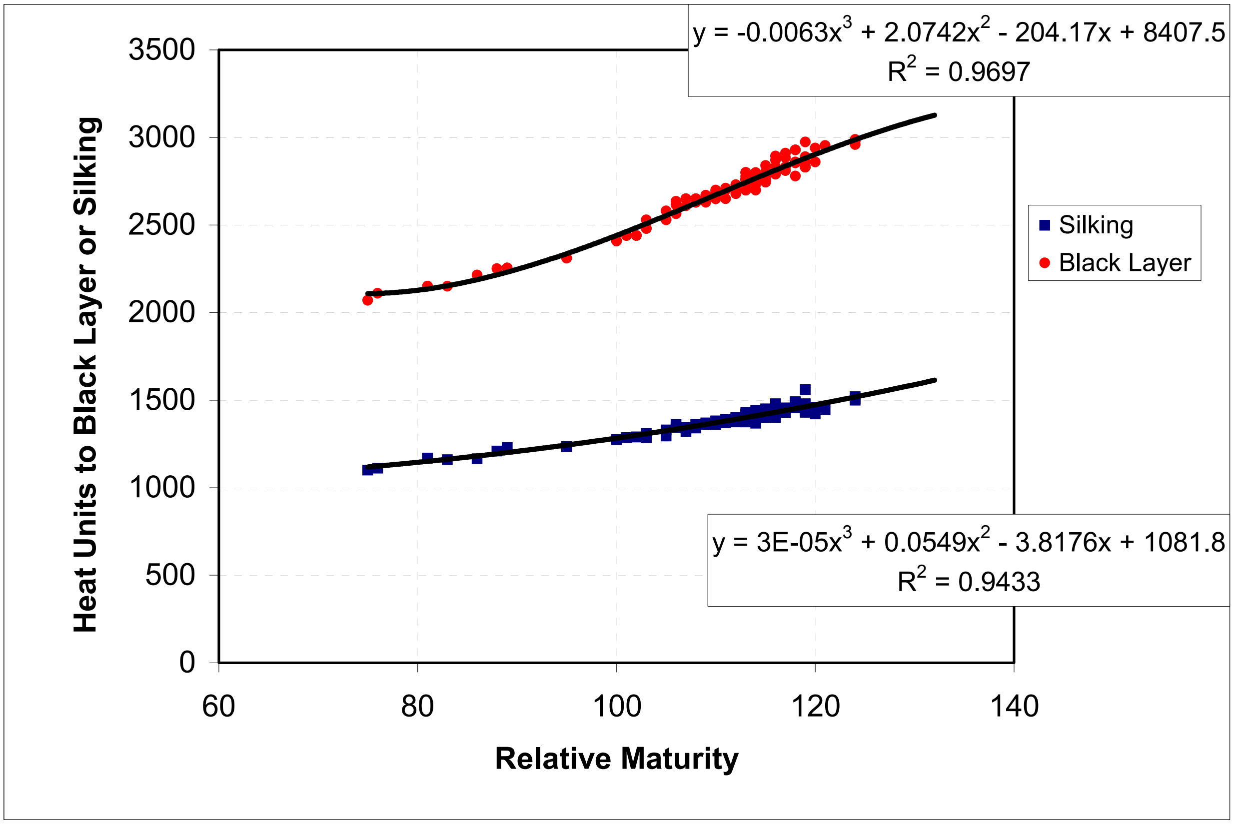

Fig. 4. Heat Units to black layer and silking based on RM of corn.

SOYBEAN. The termination date of soybean is more difficult to determine since most soybeans are day-length sensitive. Based on their normal growing period soybean varieties are categorized by Maturity Groups (MG). The smaller the MG value, the shorter the season. Farmers in Missouri plant varieties with MG values ranging from III to VII. An equation was developed to predict the expected season length of a soybean variety based on its MG, date of planting, and latitude. Data for this model (Eq. 4) was gathered from reported variety tests conducted throughout the Midwest and mid-South that utilized varieties with varying MG values and which reported soybean termination dates for the varieties in the trial.

$$L = -(0.71 \times DOY) + (0.0015 \times DOY^2) + (0.92 \times Lat) + (9.1 \times MG) + 127.6 \quad \text{(Eq. 4)}$$

where

L	= the season length [days]
DOY	= numerical day of year of planting
Lat	= latitude of location [ºF]
MG	= Maturity Group of soybean variety

Calculating Lengths for Each Growth Period

Since the farmer knows the planting date and Eqs. 3 and 4 will be used to determine crop termination, the season length is now known, thus a reasonable time framework is laid out on which to building the crop coefficient curve. Empirical studies were used to determine the number of days from planting until end of the *initial period* and from planting unit the end of the *development period* based on air temperature. This is a common sense approach and it will lengthen those periods when planting occurs early and it is still cool. Figure 5 shows the results.

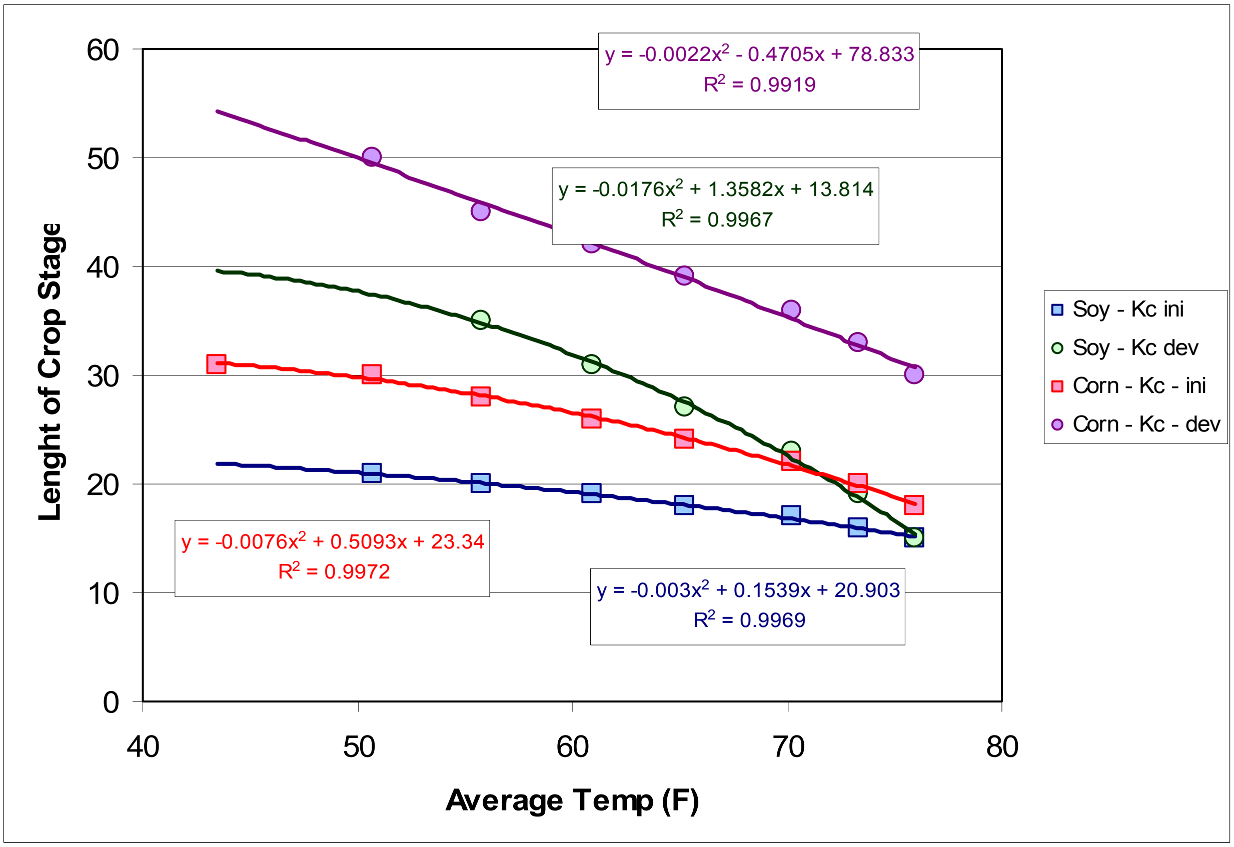

Fig. 5. The amount of time for the initial and development periods for corn and soybean based on temperature.

A period of 24 days was defaulted as the length of the *late period*. This value plus the values from Fig. 5 are used to determine the length of the mid period, which is the residual of season length minus the values for the other periods.

Conclusion

Most irrigators and irrigation programs probably use off-the-shelf crop coefficient values taken from FAO-56. This procedure allows the values to be easily modified to local conditions based on that locale's weather. An on-line Kc value generator will be added to the Missouri Irrigation website in the future (http://agebb.missouri.edu/irrigate/index.htm).

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