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A study of basal crop coefficient for wheat under humid regime from heat unit accumulations

A. CHOWDHURY, H. P. DAS and D. G. GHUMARE

Meteorological Office, Pune

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सार — इस में उत्तर-पूर्व भारत के आर्द्र क्षेत्र से आर्द्र मृदा और उष्मा एकक संचयन से आधारभूत फसल का गुणांक का अभिकलन क्रिया पद्धति प्रस्तुत की है। विकासशील पद्धति से 1976-77 से 1981-82 तक के फसल ऋतुओं का सोनालिका नामक गेहूँ की किस्म का अंकुर से पकने तक और 1982-83 और 1985-86 के फसल ऋतु के स्वतंत्र आंकड़ा समुच्चयों का उपयोग एवं परीक्षण किया है।

दूधिया अवस्था से उसके विकास की अवस्था तक उष्मा के अधिकतम अंश एकक का उपयोग पाया जाता है। फसल की दूधिया अवस्था में प्रारम्भिक फसल गुणांक का अधिकतम गुणांक 1.5 होता है। वास्तविक ई.टी. और निर्देश से तुलना के बाद बहुत अधिक गुणांक देखा गया है।

ABSTRACT. A methodology has been presented to compute basal crop coefficient from soil moisture and heat unit accumulations, for wheat in the humid region of northeast India. In developing the method data from 1976-77 to 1981-82 crop seasons for the *Sonalika* variety of wheat from germination to maturity have been used and tested on independent data set for 1982-83 and 1985-86 crop seasons.

Milk stage to physiological maturity stage is found to use maximum fraction of heat unit totals. The largest value of basal crop coefficient is about 1.5 occurring during milk stage of the crop growth. Very high correlation is noticed between the actual ET and those computed from the model.

Key words — Milk stage, Physiological stage, Heat units, Evapotranspiration, Soil evaporation, Correlation.

1. Introduction

Temperature and sunlight have profound effect on the photosynthesis of crops. In the Great Plains of USA, the temperature effect has been found to override the effects of rainfall. For estimating plant growth and development, the concept of heat units based on air temperature has been found to give encouraging results. For the crop of the same strain, heat units vary according to the date of planting and ripening (Gupta 1987).

Crop coefficients have often been used for estimating evapotranspiration (ET). Mederski *et al.* (1973) found classification of crop coefficients for accumulated heat units more useful and less variable. Hattendorf *et al.* (1988) used fraction of the thermal unit concept to obtain normalised crop coefficients.

Wheat in India is grown during winter as a major cereal rabi or winter crop. The present study has undertaken to explore, how variations in temperature above a certain threshold value affects the crop growth and its yield. Attempt is also made to determine, ET values from the crop coefficient heat unit relationship.

2. Data set

Crop and ET data for Jorhat (26° 47′ N, 94° 12′E) located at a height of 91 m above msl in the Brahmaputra valley have been utilised. The station according to Chowdhury and Sarwade (1982) belongs to per humid climate zone. Weekly data of weather elements and ET for 1976-77 to 1981-82 crop seasons were used in the analysis. During the entire period, the same strain, *i.e.*, *Sonalika* was sown in the evapotranspiration field. The model developed was tested on independent data of the station for 1982-83 and 1985-86 when wheat of the same variety was sown.

3. Heat unit concept

Among the many agroclimatic factors, temperature markedly influences physiological and morphological development in plants. In evaluating the effect of temperature on plants, concept of heat units, which is based on the assumption that the plants have a particular range of temperature requirement for their growth, development and maturity, is often used. Many investigators have computed and applied the concept of heat units as a guide in planting and harvesting multiple cropping system for effective land use,

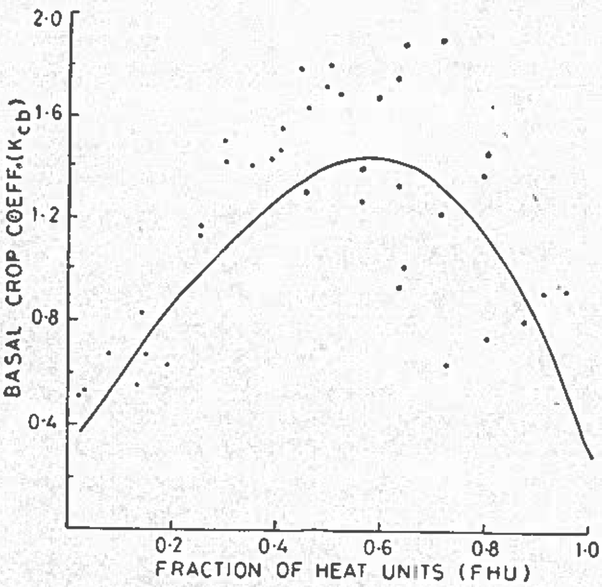
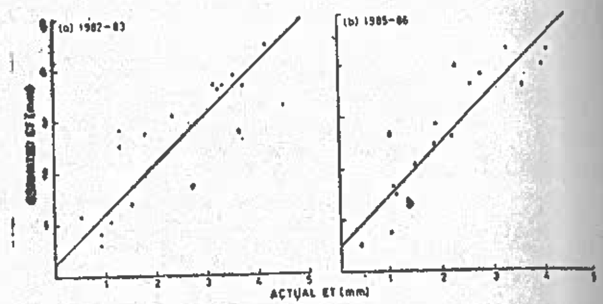


Fig. 1. Distribution of basal crop coefficient with respect to heat units



Figs. 2(a & b). Estimated and actual evapotranspiration relationship for the years: (a) 1982-83, and (b) 1985-86

The heat unit is given by mean daily air temperature *minus* the base threshold temperature. Different investigators have used different threshold temperatures according to their objectives in view. Holmes and Robertson (1959) for instance, used 10° C as the base in their studies on peas. Iwata and Okubo (1969) developed an index for corn planted on different dates also using 10°C as the base.

In the present study the base temperature of 5° C was used. This threshold is based on the presumption that plant activity gets greatly retarded below 5° C. Negative values of heat units have been taken as zero in accumulating the units. Daily values of the units have been summed for each growth stage from emergence till physiological maturity (~75% of the plants turning yellow).

Heat units were accumulated for each of the growth phases, *viz.*, germination, tillering, flowering, milking and physiological maturity. The accumulated heat units for each of the three growth intervals, *i.e.*, germination to tillering, germination to flowering, germination to milking were then divided by the accumulated units from germination to physiological maturity to obtain fraction of heat units (FHU) for these development stages.

4. Crop growth and utilisation of heat units

The total heat units utilised by the *Sonalika* variety of wheat is given in Table 1. The table also summarises the fraction of total growing season heat units accumulated from germination to the three selected growth intervals mentioned above. The total heat units (germination to maturity) varied from nearly 1300 to 1500 heat units with a mean of about 1440 units. The fraction of thermal units for any of the three growth intervals varied within very narrow limits. From germination to tillering the heat units used is about 17% of the total heat units needed for growth. The FHU is about 40% for the period up to flowering and 60% till milking. By and large maximum heat units, *i.e.*, about 40% are utilised by the wheat plant between milking and maturity.

5. Basal crop coefficient

For any stage of growth, normally, the crop coefficients are calculated as the ratio of actual evapotranspiration (ET), to the reference or potential evapotranspiration (PET). Wright (1982) has, however, advocated use of another crop coefficient called the '*Basal crop coefficient*'. He defined basal crop coefficient as a situation when the soil evaporation was minimal though availability of soil moisture within the root zone of the crop did not limit the plant or its growth. The basal crop coefficient, thus, makes use of available soil moisture at the root zone.

The method of calculating the basal crop coefficient K_{cb} is given below :

In these calculations, first a factor called "adjustment factor for available soil water", K_a, is computed. This is given by :

$$K_a = 1, \text{ when ASM/FC} \geqslant 0.5$$

$$K_a = (\text{ASM/FC})/0.5 \text{ if ASM/FC} < 0.5 \quad (1)$$

where, ASM is the available soil moisture and FC the field capacity of the soil. In case when ASM/FC is less than 0.5, K_a is less than one. The basal crop coefficient :

$$K_{cb} = (\text{ET/PET})/K_a \quad (2)$$

The effective root zone of the wheat crop is assumed as 60 cm. As such, soil moisture measurement at this depth has been considered. The PET values were calculated by using Penman-Monteith formula :

$$\text{PET} = W.R_n + (1-W) f(u). (e_a - e_d) \quad (3)$$

TABLE 1

Heat units in different growth stages as fraction of total growing period heat units

Year	Germination to Tillering	Germination to Flowering	Germination to Milking	Total heat units from germination to maturity
	(Fraction of heat units)			
1976-77	0.16	0.41	0.55	1487
1977-78	0.17	0.40	0.56	1325
1978-79	0.17	0.44	0.64	1519
1979-80	0.15	0.50	0.63	1375
1980-81	0.17	0.46	0.63	1375
1981-82	0.17	0.43	0.60	1532
Average	0.17	0.44	0.60	1435

where, W is temperature related weighing factor,

R_n is net radiation equivalent evaporation (mm/day),

$f(u)$ is the wind related factor,

e_a is the actual vapour pressure (mm), and

e_d is the saturation vapour pressure (mm).

In computing K_a and K_{cb}, only weeks with no rainfall were considered first. The sample thus available was rather small. To supplement the data, periods when the weekly rainfall was up to 15 mm were also considered. A term K_s to account for soil evaporation during the three consecutive weeks following rain of such an amount was calculated as below :

$K_s = 0.8\,(1.5 - K_{cb})$ for 1st week following rain,

$K_s = 0.5\,(1.5 - K_{cb})$ for 2nd week following rain,

$K_s = 0.3\,(1.5 - K_{cb})$ for 3rd week following rain (4)

The weights 0.8, 0.5 and 0.3 in the above equations were chosen for the medium textured soil at Jorhat (*cf.* Wright 1985). The number 1.5 in the parenthesis represent the mean maximum value of K_{cb} determined from the earlier data set when only dry weeks were considered. The K_{cb} values in these equations were obtained from Eqn. (6), developed from FHU and K_{cb} relationship when the weekly rainfall was zero. The evaporation for the week (with rainfall up to 15 mm) was obtained as $K_s \times$ PET. In computing evaporation the cases when the total evaporation during the three weeks following the rains exceeded the weekly rainfall were neglected. ET values are then calculated as :

$$\mathrm{ET} = \mathrm{ET}_l - K_s \times \mathrm{PET} \quad (5)$$

where, ET_l represents the lysimetric values. The K_{cb} for rainfall up to 15mm cases was then calculated from Eqn. (2) by replacing ET by ET_l.

The K_{cb} values for all periods (*i.e.*, dry weeks and those with rainfall up to 15mm) were then used in producing the final basal crop coefficient curve through regression analysis.

* Figures in the parenthesis represent partial t values.

TABLE 2

Summary of basal crop coefficient from germination to maturity

Year	Germination to tillering	Tillering to flowering	Flowering to milking	Milking to maturity
1976-77	0.53	1.04	1.79	0.78
1977-78	0.69	1.26	1.73	1.24
1978-79	0.59	1.25	1.66	1.01
1979-80	0.57	1.20	1.24	0.88
1980-81	0.54	0.94	1.19	0.97
1982-82	0.40	0.90	1.40	0.65
Average	0.55	1.09	1.50	0.92

It may be mentioned that in this study the maximum value of basal crop coefficients (K_{cb}) would be realised when actual evapotranspiration is significantly larger than its potential value, while at the same time, the available soil moisture at the root zone is at least half of its maximum capacity. On the other hand, the lowest value of K_{cb} would be attained when evapotranspiration is small as compared to PET but available soil moisture is significantly large and near the field capacity.

6. Distribution of basal crop coefficient

In the first instance relationship between K_{cb} and FHU for the weeks without any rainfall was developed. A third degree curve in FHU was fitted to K_{cb}. Retaining only those terms with partial coefficient significant at 1% level the following equation was obtained :

$$K_{cb} = 0.32 + 2.90\ \mathrm{FHU} - 2.93\ \mathrm{FHU}^3$$
$$(11.22)^* \qquad (9.68)^*$$
$$r = 0.81 \quad (6)$$

The plot of K_{cb} *versus* FHU of the combined data is shown in Fig. 1. Fitting again a second degree curve and retaining only the statistically significant terms as before the following equation is obtained :

$$K_{cb} = 0.19 + 4.47\ \mathrm{FHU} - 4.24\ \mathrm{FHU}^2$$
$$(10.06)^* \qquad (9.29)^*$$
$$r = 0.76 \quad (7)$$

It may be seen that introduction of cases with rainfall up to 15 mm change the FHU-K_{cb} relationship curve from cubic to a parabola. There is also marginal reduction in the correlation coefficient.

The regression curve shows a typical mono-model pattern with $K_{cb} \simeq 1.5$ corresponding to a FHU value of 0.6 at the milk stage. Such single peak value of crop coefficient is a characteristic feature of nearly all field crops (Amos *et al.* 1989).

Stagewise mean values of K_{cb} are given in Table 2. On an average the K_{cb} value appears to attain the maximum of about 1.5 between the flowering and milk stages. After the milk phase, values remain close to 1.0 till maturity but subsequently decreases sharply when senescence or abscision commences. High values of crop coefficients are not uncommon, for instance, Olderman and Frere (1979) observed value of crop coefficients as high as 1.4 for rice crop in Thailand.

7. Computed and actual (lysimetric) ET : A comparison

The values of K_{cb} could be used to estimate evapotranspiration (ET_e) following Wright (1985) :

$$ET_e = (K_{cb} \times K_a + K_s) \text{ PET}$$

In the study, the model developed was applied to the wheat (*Sonalika* variety) for the crop seasons 1982-83 and 1985-86. The actual (lysimetric) and estimated evapotranspiration values were then subjected to χ^2-test. The χ^2 values were not significant, confirming that the estimated values were not significantly different from the actual ones. The estimated ET values were regressed with lysimetric values for the above two years. The results are shown in Figs. 2(a&b). The following relationship between these two could be established:

$$Y = 0.96 + 0.23\ X \qquad (8)$$

$r = 0.88$ for 1982-83

$$Y = 0.99 + 0.54\ X \qquad (9)$$

$r = 0.87$ for 1985-86

The correlations were highly significant and clearly established the utility of fraction of heat unit as a crop coefficient base in estimating evapotranspiration, in any stage of the growth from germination to harvest.

8. Conclusions

The following conclusions could be drawn from the study:

(*i*) The basal coefficient is a better parameter than the ordinary crop coefficient in crop growth studies.

(*ii*) The maximum utilisation of the heat units occur from milking to physiological maturity stage of the crop.

(*iii*) The maximum values of basal crop coefficient for wheat occurs during the milk stage and is about 1.5.

(*iv*) Evapotranspiration can be easily estimated from the soil moisture and potential evapotranspiration.

(*v*) The relation between basal crop coefficient and the fraction of the heat unit is non-linear.

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