Influence of actual evapotranspiration, growing degree days and bright sunshine hours on yield of finger millet

C. S. PATIL and B. PUTTANNA
Meteorological Centre, Bangalore - 560 001, India
(Received 28 March 2007, Modified 26 February 2009)
e mail : cspatilmet@rediffmail.com

ABSTRACT. Based on the result of an experiment conducted for three years from 1997-1999 during Kharif, under rainfed conditions, a model has been generated for relating crop coefficient of ragi with time at Bangalore. The peak value of crop coefficient was found to be 1.02 on 66th day after sowing. The multiple regression equation was also generated based on the accumulated values of actual evapotranspiration (AET), growing degree days (GDD) and bright hours of sunshine (BHS) from sowing to physiological maturity, using the field experimental data for the period 1998-2005. This multiple regression equation can be applied to forecast the yield of finger millet under rainfed conditions. This model was validated for the crop grown during Kharif 2005.

Key words – Finger millet, Actual evapotranspiration, Growing degree days, Bright hours of sunshine, Crop coefficient, Multiple regression equation.

1. Introduction

Finger millet (Elusine coracana Gaertn) is one of the staple food crop of Southern Karnataka and also valued for its fodder to meet the requirements of the domestic livestock. The early prediction of yield is very important for planning and decision making purposes at the national and international levels. Yield prediction would also be useful in the planning of export - import and continuous monitoring of potential areas of crop failure.

Finger millet is mainly grown in rainfed area. It experiences soil moisture stress during prolonged dry spells of southwest monsoon. To overcome the soil moisture stress during dry spells at critical stages, a knowledge of crop coefficient (Kc) is necessary to plan agricultural operations like protective irrigation etc, Doorenbos and Pruitt (1977) showed the significance of Kc for assessment of crop water requirement for irrigation scheduling.

Weather affects crop growth differently at different phonological stages. Ganeshan and Ahobala Rao (1989) found that the duration to flowering is positively correlated with average temperatures and average evaporation in the case of finger millet. The crop growth...
**Fig.1.** Crop coefficient for Finger millet during 1997-1999

![Graph of Kc for Finger millet](image)

\[ y = -0.0097x^2 + 0.1821x + 0.1646 \]

\[ R^2 = 0.9055 \]

**TABLE 1**

Accumulated values of AET, GDD & BHS during growth period

| Date of sowing | Date of Physiological Maturity | AET (mm) | GDD (degree days) | BHS (hours) | Yield (q/ha) | WUE (kg/ha/mm) | HUE (kg/ha/degree day) |
|----------------|--------------------------------|----------|-------------------|-------------|--------------|----------------|------------------------|
| 13 Aug 1997    | 28 Nov 1997                    | 279.2    | –                 | 638.5       | –            | –              | –                      |
| 13 Aug 1998    | 30 Nov 1998                    | 297.9    | 1403.9            | 574.4       | 27.82        | 9.34           | 1.98                   |
| 15 Aug 1999    | 01 Dec 1999                    | 310.7    | 1400.1            | 684.8       | 30.86        | 9.93           | 2.20                   |
| 03 Aug 2000    | 23 Nov 2000                    | 319.6    | 1440.1            | 624.5       | 31.11        | 9.73           | 2.16                   |
| 29 Jul 2001    | 25 Nov 2001                    | 345.0    | 1556.0            | 610.2       | 42.74        | 12.39          | 2.75                   |
| 01 Aug 2002    | 14 Nov 2002                    | 325.0    | 1446.0            | 571.4       | 28.26        | 8.69           | 1.95                   |
| 24 Jul 2003    | 16 Nov 2003                    | 362.7    | 1524.0            | 586.9       | 37.26        | 10.27          | 2.44                   |
| 24 Jul 2004    | 14 Nov 2004                    | 357.5    | 1449.2            | 661.0       | 40.97        | 11.46          | 2.83                   |
| 11 Aug 2005    | 06 Dec 2005                    | 329.3    | 1453.3            | 548.9       | 30.15        | 9.15           | 2.07                   |
| Average values |                               | 325.2    | 1459.2            | 611.2       | 33.65        | 10.12          | 2.29                   |
simulation models currently being used extensively for predicting the yield of crops have large input data requirements and some are difficult to use because of being very detailed (Whisler et al., 1986). Muralidhara and Rajegowda (2002) developed stocheometric crop weather models to predict the finger millet grain yield. Compared to these models, statistical crop weather models are practical tools for the analysis of crop responses to weather.

The objective of the present study is to develop a regression equation relating crop coefficient with time. Also, an attempt has been made to generate multiple regression models based on the accumulated values of AET, GDD and BHS from sowing to physiological maturity to predict the yield of finger millet.

2. Data and methodology

In the present study, data on finger millet variety GPU 28 grown at Agrometeorological research unit of IMD, GKVK Campus, Bangalore (12° 58' N, 77° 35' E, 930m asl) in Karnataka state for three years during the Kharif season between (1997 - 1999) were analyzed to study crop coefficient during various growth stages of the crop. The crop was raised on red sandy loam soils following the recommended package of practices of University of Agricultural Sciences, Bangalore. The crop coefficient (Kc) was calculated using the following relationship:

$$ Kc = \frac{AET}{PET} $$

Potential evapotranspiration (PET) values were calculated using Penman's modified formulae. The data on meteorological parameter from the adjacent agrometeorological observatory was used. The actual evapotranspiration (AET) was measured through gravimetric lysimeters located in the crop field during the years (1997-1999). AET was calculated for the period (2000-2005) from the calculated values of PET and Kc.

Daily values of maximum and minimum temperatures were used to calculate the heat units namely growing degree day (GDD) keeping 10°C as base temperature from sowing to physiological maturity.

$$ GDD = \frac{[(T_{max} + T_{min})/2] - T_b}{10} $$

where

- $T_{max}$ = Maximum temperature
- $T_{min}$ = Minimum temperature
- $T_b$ = Base temperature.

Maximum and minimum temperature data for the month of October 1997 is not available. Harvesting data of 1997 for the finger millet is also not available as the GKVK campus, Bangalore recorded 200 mm and 65 mm of rainfall on 1st and 2nd October 1997. Because of this very heavy rainfall the crop might have damaged partly.

Multiple regression equation was generated based on the accumulated values of AET, GDD & BHS (Table 1) from the date of sowing to date of physiological maturity as independent parameters and yield as dependant parameter and was used to estimate the yield of finger millet. This multiple regression was validated for the crop grown during Kharif 2005 at GKVK campus, Bangalore.

3. Results and discussion

3.1. Crop coefficient

A knowledge of crop coefficient is necessary to determine water requirement of the crop. Fig. 1 shows variation in crop coefficient (Kc) with time, in weeks after sowing (WAS) during the growth of finger millet. When Kc values were fitted to time in WAS, the following non-linear relationship ($R^2 = 0.90$) was obtained:

$$ Kc = 0.1646 + 0.1821 \times (WAS) -0.0097 \times (WAS)^2, \quad R^2 = 0.90 $$

Using this equation, it is possible to estimate Kc values at any time, during different stages of crop growth. The maximum value of Kc was found to be 1.02 on 28th DAS. Das et al., (1996) found the highest value of Kc i.e., 1.10 for pearl millet at Hisar and occurred at 9th WAS in the flowering stage. Chaudhari et al., (1999) have reported Kc values for major crops of Gujarat region.

3.2. Consumptive use of water (AET) and water use efficiency (WUE)

The AET of finger millet varied between 279.2 mm and 362.7 mm (Table 1). This variation may be due to weather conditions prevailing during the growth period in different years. Doorenbos and Kassam (1979) also recognized climate as one of the important factors determining crop water requirements needed for unrestricted optimum growth and yield. The level of evapotranspiration is related to the evaporative demand of
the air. On an average the crop need about 325.2 mm of water during the growth period. The variation of average weekly AET with respect to WAS is shown in Fig.2.

The yield varied from 27.82 q/ha during 1998 to 42.74 q/ha during 2001 with a mean yield of 33.65 q/ha.

The seed yield and evapotranspiration showed a positive and significant ($R^2 = 0.69$) linear relationship.

$$Y = 0.208(AET) - 34.92, \quad R^2 = 0.69$$

The scatter between grain yield and evapotranspiration data ($R^2 = 0.69$) was probably due to the variation in rainfall amount and distribution among the growing seasons. Zhang and Oweis (1998) reported a linear relationship of grain yield with seasonal evapotranspiration for wheat and also by Stewart et al., (1983) for sorghum. Hati et al., (2001) also reported a significant relationship ($R^2 = 0.79$) of seed yield and total evapotranspiration for Indian mustard.

The lowest water use efficiency (WUE) of 8.69 kg/ha/mm was observed in 2002 and while highest value of 12.39 kg/ha/mm was in the 2001. The wide variation of WUE may be attributed to the varying crop growing environments in different years.

3.3. Growing degrees and bright hours of sunshine

GDD is widely used for describing the temperature response on growth and development of the crops. The crop requires about 1459.2 heat units (GDD) for its maturity. The following equation was obtained between the yield of grain ($Y$) and accumulated heat units ($X$), it gives

$$Y = 0.0791 \text{(GDD)} - 81.43, \quad R^2 = 0.57$$

Mathan (1996) found the values of GDD ranging from 1390 to 1467 for ragi. Ganeshan et al., (1988) reported a linearly correlation between biomass production and accumulated GDD.
TABLE 2

| Phonological stages     | AET   | GDD  | BHS  |
|-------------------------|-------|------|------|
| Sowing to tillering     | 0.10  | -0.37| -0.33|
| Ear emergence           | 0.32  | -0.19| -0.20|
| 50% Flowering           | 0.60* | -0.02| -0.01|
| Grain formation         | 0.67* | 0.43 | 0.24 |
| Maturity                | 0.52  | 0.79*| 0.53 |

*Significant at 5% level.

The heat use efficiency (HUE) is ranged from 1.95 kg/ha/degree day to 2.83 kg/ha/degree day as observed in Table 1. Experiment conducted at Coimbatore recorded the values of HUE from 0.68 kg/ha/degree day to 2.84 kg/ha/degree day (Mathan, 1996).

The grain yield and bright hours of sunshine are found to be positively correlated. The average value of bright sunshine was 611.2 hours. Mathan (1996) reported the range of BHS varied from 577.7 hours to 802.7 hours.

3.4. Multiple regression model and its validation

The following multiple regression model was generated based on the accumulated values of AET, GDD & BHS from sowing to physiological maturity to predict the yield of finger millet.

\[ Y = -125.76 + 0.086 \times (\text{AET}) + 0.064 \times (\text{GDD}) + 0.06 \times (\text{BHS}) \]

\[ R^2 = 0.93 \]

The model has been validated for the crop grown during Kharif 2005 at GKVK campus, Bangalore and the predicted value was found to be 29.40 q/ha where the actual value was 30.15 q/ha. The regression equation containing the parameters AET, GDD & BHS is found to be a good predicting model.

It is found that the AET is significantly correlated with grain yield during flowering and grain formation stage. GDD is significantly correlated with grain yield during maturity stage and the correlation between BHS and grain yield is 0.53 during maturity stage (Table 2).

4. Conclusion

(i) Based on the crop coefficient at specific stages, the water requirement for the crop may be worked out so that in command areas highest yield can be realised with the management of available water.

(ii) The highest value of crop coefficient was 1.02 on 66th day after sowing.

(iii) The average values of AET, GDD and BHS 325.2 mm, 1459.2 degree days and 611.2 hours respectively.

(iv) The multiple regression model may be used for yield forecasting of finger millet under rainfed conditions at Bangalore.

References

Chaudhari, G. B., Patel, K. I., Shekh, M. A. and Savani, M. B., 1999, “Crop coefficient of major crops of middle Gujarat region”, *J. of Agrometeorology*, 1, 2, 167-172.

Das, H. P., Kashyapi, A. and Apte, S. G., 1996, “Evapotranspiration and soil moisture balance in relation to yield of pearl millet”, *Mausam*, 47, 33-80.

Doorenbos, J. and Pruitt, W. O., 1977, “Guidelines for predicting crop water requirements”, *Irrigation and Drainage paper No. 24, FAO*, 35-41.

Doorenbos, J. and Kassam, A. H., 1979, “Guidelines for predicting crop water requirements”, *Irrigation and Drainage paper no. 33, FAO Rome*, p193.

Ganeshan, G. S. and Ahobala Rao, H. R., 1989, “Duration to and height at the time of flowering in relation to selected wither parameters; A study in the case of ragi over Bangalore”, *Mausam*, 40, 3, 259-262.

Ganeshan, G. S., Ahobala Rao, H. R. and Mathrubutheshwaran. G., 1988, “A study of the influence of selected weather parameters on biomass production in ragi”, *Mausam*, 39, 2, 197-200.

Hati, K. M., Mandal, K. G., Misra, A. K., Ghosh, P. K. and Acharya, C. L., 2001, “Evapotranspiration, water use efficiency, moisture use and yield of Indian mustard (Brassica juncea) under varying levels of irrigation and nutrient management in Vertisol”, *Indian Journal Agricultural Sciences*, 71, 10, 639-643.

Mathan, K. K., 1996, “Effect of Soil temperature and certain weather parameters on the growth and yield of ragi”, *Mausam*, 47, 3, 281-286.
Muralidhara, K. S. and Rajegowda, M. S., 2002, “Stocheometric crop weather model to predict the finger millet grown yield”, *J. of Agrometeorology, 4*, 1, 53-57.

Stewart, B. A., Musick, J. T. and Dusek, D. A., 1983, “Yield and water use efficiency of grain Sorghum in a limited irrigation dry land system”, *Agronomy Journal, 75*, 629-634.

Whisler, F. D., Acook, B., Baker, D. N., Fye, R. E., Hodges, H. F., Lambert, L. R., Lemmon, H. E., Mckikinion, J. M. and Reddy, V. R., 1986, “Crop simulation in organic systems”, *Advances in Agronomy, 40*, 141-208.

Zhang, H. and Oweis, T. 1998, “Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region”, *Agriculture water management, 38*, 195-211.