Journal of Agrometeorology 14 (2) : 123-129 (December 2012)

Determination of crop coefficients and optimum irrigation schedules for bidi tobacco and pearl millet crops in central Gujarat

B. KRISHNA RAO[1], GOPAL KUMAR[1], R.S. KUROTHE[1], VYAS PANDEY[2], P.K. MISHRA[3] A.K. VISHWAKARMA[1] and M.J. BARAIYA[1]

[1]*Central Soil and Water Conservation Research and Training Institute, Research Centre, Vasad-388306, Anand, Gujarat*

[2]*Department of Agricultural Meteorology, Anand Agricultural University, Anand-388110, Gujarat*

[3]*Central Soil and Water Conservation Research and Training Institute, 218 Kaulagarh Road, Dehradun-248195, Uttarakhand*

Email: b_krishnarao@rediffmail.com

ABSTRACT

An attempt was made to determine the rate of ETc and crop coefficients during various growth stages of bidi tobacco and pearl millet crops in central Gujarat by water balance approach. From the crop coefficients and meteorological data, optimum irrigation schedules with furrow and drip irrigations were developed. The duration of various growth stages of bidi tobacco crop identified as 30, 40, 50, 30 days for initial, development, mid season and late season respectively. The crop coefficients for these periods Kc initial, Kc mid, Kc end were found to be 0.42, 0.85 and 0.44 all in respective order. Similarly for the pearl millet crop identified as 15, 25, 30, 15 days for initial, establishment, maturity and late season respectively. The crop coefficients for these periods Kc initial, Kc mid, Kc end were found to be 0.33, 0.73 and 0.42 respectively. The identified duration of crop growth stages and respective derived crop coefficients for various growth stages of bidi tobacco and pearl millet crops will be useful to estimate crop water requirements and further developing optimum irrigation schedules for achieving higher water productivity.

Key words: bidi tobacco, pearl millet, crop coefficients, furrow, drip, irrigation, schedules.

Crop evapotranspiration (ETc) is used to determine the water requirement of the crop and developing irrigation schedules. Measurement of ETc being difficult, the same is commonly estimated using the meteorological data. A common procedure for estimating ETc is to first estimate reference crop evapotranspiration (ETc) from weather data and then to apply empirical crop coefficient (Kc), i.e. the ratio of crop evapotranspiration (ETc) to reference crop evapotranspiration (ETc). Different methods have been attempted by many scientists to estimate the ETc for different crops in different climatic conditions (Khandelwal *et al*. 1999; Pandey *et al*. 2008; Gorantiwar *et al.* 2011). For estimating ET0, Penman- Monteith method is most preferred as it suits a wide variety of climatic conditions (Kashyap and Panda, 2001; Khandelwal & Pandey, 2008; Sahoo *et al*. 2009). The FAO adopted this method as a global standard (Allen *et al.* 1998). Sikka *et al.* (2001) also used this method of computing ET_0 because of its better performance in hilly region of Nilgiris. Although crop co-efficient values for different crops grown under different climatic conditions as suggested by Doorenbos and Pruitt (1977) are used where locally measured data are not available; Allen *et al.* (1998) have suggested that these values need to be derived empirically for each crop based on the local conditions.

In Central Gujarat, the major crops, viz. bidi tobacco (*Nicotiyana tabaccum)*, pearl millet (***Pennisetum glaucum)***, cotton *(Gossypium* sp.), *castor* (***Ricinus communis)*** are commonly grown both under rainfed and irrigated conditions. Under irrigated conditions, bidi tobacco-pearl millet is the major cropping system, which is practiced by the famers. Mostly, farmers of this zone raise the bidi tobacco seedlings from second fortnight of July to first fortnight of September. Planting is done in second fortnight of September. Tobacco is harvested by the end of February and during first fortnight of March, sowing of pearl millet is completed. This crop continues up to end of May. These crops are growing in post monsoon season (rabi and summer season) and water requirement are completely met from the irrigation. The yield of these crops varies and suffers due to uneven water distribution and improper irrigation scheduling. The study

Table 1: Reference(ET_0), actual evoptranspiration(ET_C) and crop coefficients(Kc) during various growth stages of bidi tobacco crop.

Crop growth stages	2010-11			2011-12			Average		
	ET_0	ETc	Kc	ET_0	ETc	Kc	ET_0	ETc	Kc
Initial	3.28	1.59	0.42	3.71	1.55	0.43	3.49	1.57	0.43
Crop development	3.13	2.25	0.77	3.21	2.28	0.76	3.17	2.27	0.76
Mid season	2.61	2.68	0.86	2.88	2.64	0.85	2.75	2.66	0.84
Late season	2.9	1.43	0.45	2.91	1.4	0.44	2.91	1.42	0.44

Table 2: Reference(ET_0), actual evoptranspiration(ET_C) and crop coefficients(Kc) during various growth stages of pearl millet crop.

Crop growth stages	2010-11			2011-12			Average		
	ET_0	ETc	Kc	ET_0	ETc	Kc	ET_0	ETc	Kc
Initial	5.5	1.70	0.31	5.02	1.70	0.34	5.26	1.70	0.33
Crop development	6.25	2.60	0.41	5.67	2.44	0.43	5.96	2.52	0.42
Mid season	7.55	5.31	0.72	6.39	4.59	0.74	6.97	4.95	0.73
Late season	7.73	3.28	0.42	7.49	3.04	0.41	7.61	3.16	0.42

on evapotranspiration rate of these crops, crop coefficients, and optimum irrigation schedules are immense importance for optimal water utilization, higher yields and quality. Hence an attempt has been made to determine the rate of ETc and crop coefficients during various growth stages of bidi tobacco and pearl millet crops in central Gujarat.

MATERIALS AND METHODS

This study was conducted during 2010-11 and 2011-12 at farmer's field neighbouring to Central Soil & Water Conservation Research & Training Institute, Research Centre, Research farm, Vasad, Anand District of Gujarat, India. This field is located in Mahi basin of Central Gujarat which is 18 km from Anand town and 22 km from Vadodara city of Gujarat. The soil type is loose sandy loam soil. Tobacco crop was transplanted during second fortnight of September (on 18th September in 2010 and 16th September in 2011) and pearl millet crop was sown during first fortnight of March (on 5th March in 2011 and 3rd March in 2012). Recommended agronomic practices were followed for both the years.

Crop growth stages

The crop period was divided into four distinct growth stages: initial, crop development, mid-season and late season (Dorrenbos and Pruitt, 1975, Allen *et al.,* 1998). Based on the information provided by Allen *et al.,* (1998) and actual growth in field, the various growth stages for tobacco and pearl millet crops were identified.

Evapotranspiration

The evpotranspiration (ETc) in this study was measured by field water balance approach. The amount of irrigation water given to the field for each irrigation and their intervals were noted and effective rainfall (ER) was estimated by USDA method with slight modification as suggested by Rao & Rajput (2008). The irrigation water was given at 50% depletion of moisture at field capacity, assuming 60% and 90% irrigation efficiency of furrow and drip irrigations respectively. Based on the moisture content measured by using gravimetric method, it is observed that, the changes in soil moisture before the irrigation and end of the irrigation period is constant. Actual evapotranspiration (ETc) for the different growth stages of bidi tobacco and pearl millet were worked out using following equation.

$$ET_{ci} = IR_i \eta + ER_i + \sum_{k=1}^{n} (M_{bki} - M_{eki}).A_k.D_k$$

Where,

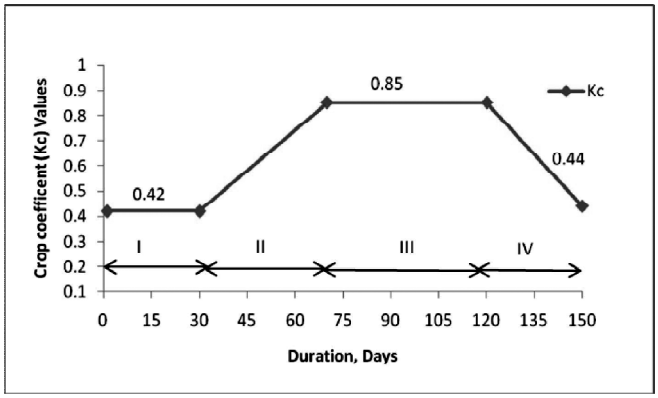
ET_{ci} = Crop evapotranspiration during the i^{th} period

IR_i = Irrigation water applied in i^{th} irrigation

= Field application efficiency

ER_i = Effective rainfall during the i^{th} period

M_{bki} = Moisture percentage at the beginning of i^{th} period in the k^{th} layer of the soil



Note: I: initial stage, II: crop development stage; III: mid-season stage; IV: late season stage

Fig. 1: Crop growth stages and crop coefficients for bidi tobacco.

M_{eki} = Moisture percentage at the end of i^{th} period in the k^{th} layer of the soil

A_k = Apparent specific gravity of the k^{th} layer of the soil

D_k = Depth of the k^{th} layer of the soil with the root zone(mm)

n = Number of soil layers in the rootzone, in the increment of 15 cm

Crop coefficients

The daily meteorological data of temperature (maximum and minimum), relative humidity, wind velocity and sunshine hours were collected from the meteorological observatory located within the research farm and suitable adjustments were made according to the FAO Penman-Monteith recommendations (Allen *et al.,* 1998) and reference evapotranspiration for the different growth stages of bidi tobacco and pearl millet (bajra) were worked out. The crop co-efficient (Kc) was calculated using following relationship.

$$Kc\ i = \frac{ET_{ci}}{ET_{0i}}$$

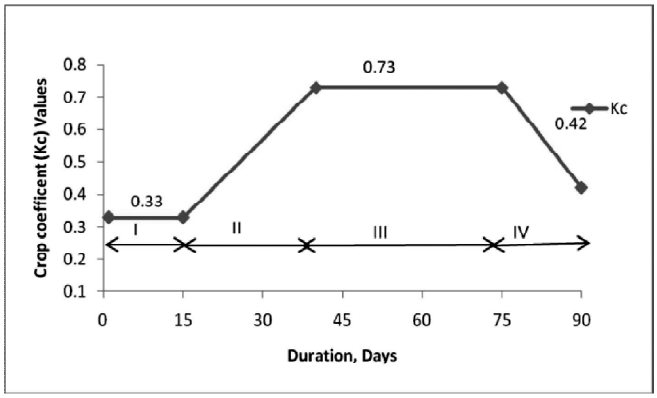
Where,

Kc = Crop coefficients during the i^{th} period

ET_{0i} = Reference evapotranspiration during the i^{th} period

Irrigation schedules

For developing optimum irrigation schedules, reference evapotranspiration during the tobacco and pearl millet (bajra) crop periods were estimated by FAO Penman-



Note: I: initial stage, II: crop development stage; III: mid-season stage; IV: late season stage

Fig. 2: Crop growth stages and crop coefficients for pearl millet.

Monteith method (FAO 56) (Allen *et al.,* 1998) from the meteorological data of 1982-2011. The actual evpotranspiration of the crop was estimated by the developed crop coefficients. The effective rainfall was estimated by USDA method with slight modification as suggested by Rao & Rajput (2008). Once the evapotranspiration (ETc_i) and effective rainfall (ER_i) for different crops in a given week (i^{th}) are known, the net irrigation water requirement (NIR_i) was computed as follows.

$$NIR_i = ETc_i - ER_i$$

The gross irrigation requirement (GIR) was calculated using the following equation.

$$GIR_i = \frac{NIR_i}{\eta}$$

Where, η = Application efficiency

Based on the estimated gross irrigation requirement, optimum schedules were developed under furrow and drip irrigation for these crops.

RESULTS AND DISCUSSION

Crop growth stages

Based on the actual growth in the field, various growth stages for bidi tobacco and pearl millet crops were identified. For tobacco crop, the initial stage started from transplanting to 4-6 new leaves development, which was completed within 30 days after transplanting. The

Table 3: Irrigation requirement and schedules for bidi tobacco.

Week No	ET_0, mm	Rainfall, mm	Kc	ETc, mm	ER, mm	NIR, mm	GIR –F., mm	F. Irr. Schedules Depth, mm	GIR –drip irri., mm	GIR by drip, in lit.	Drip system (#) operating time Hr:Min
38	30.06	33.43	0.42	12.62	33.43	0.00	0.00	@	0.00	0.00	0:00
39	30.89	20.83	0.42	12.97	20.83	0.00	0.00		0.00	0.00	0:00
40	33.16	16.53	0.42	13.93	16.53	0.00	0.00	50	0.00	0.00	0:00
41	31.79	7.91	0.42	13.35	7.91	5.44	9.06		6.05	3.02	0:45
42	30.57	2.62	0.67	20.48	2.62	17.86	29.77	70	19.84	14.09	3:30
43	30.60	2.19	0.77	23.56	2.19	21.37	35.61		23.74	18.99	4:45
44	30.70	0.00	0.77	23.64	0.00	23.64	39.40		26.27	21.01	5:15
45	29.88	0.10	0.77	23.01	0.10	22.91	38.18	75	25.45	20.36	5:00
46	27.08	0.46	0.77	20.85	0.46	20.39	33.98		22.66	18.12	4:30
47	25.48	0.92	0.77	19.62	0.92	18.70	31.17	75	20.78	16.62	4:10
48	25.34	0.00	0.85	21.54	0.00	21.54	35.90		23.94	19.15	4:50
49	24.04	0.00	0.85	20.43	0.00	20.43	34.05		22.70	18.16	4:30
50	23.33	0.30	0.85	19.83	0.30	19.53	32.54	75	21.70	17.36	4:20
51	23.61	0.00	0.85	20.07	0.00	20.07	33.45		22.30	17.84	4:30
52	23.91	0.50	0.85	20.32	0.50	19.82	33.03	75	22.02	17.62	4:30
1	24.97	1.20	0.85	21.23	1.20	20.03	33.38		22.25	17.80	4:30
2	24.45	2.90	0.85	20.78	2.90	17.88	29.80	75	19.86	15.89	4:00
3	25.27	0.34	0.49	12.38	0.34	12.05	20.08		13.38	10.71	2:40
4	27.00	0.00	0.44	11.88	0.00	11.88	19.80	70	13.20	10.56	2:40
5	28.93	0.00	0.44	12.73	0.00	12.73	21.21		14.14	11.31	2:50
6	30.14	0.00	0.44	13.26	0.00	13.26	22.10		14.74	11.79	3:00
7	33.73	0.00	0.44	14.84	0.00	14.84	24.73		16.49	13.19	3:20
Total irrigation requirement by furrow irrigation							557.26	555			

Note: ET_0: Reference Evapotranspiration; Kc: Crop Coefficent; ETc : Actual Evapotranspiration; ER: Effective Rainfall; NIR: Net irrigation requirement; GIR: Gross irrigation requirement; F: Furrow;

*: Transplanting irrigation; # 16 mm diameter inline lateral with 4 l hr^{-1} per emitter discharge capacity

Table 4: Irrigation requirement and schedules for summer pearl millet crop.

Week No	ET_0, mm	Rainfall, mm	Kc	ETc, mm	ER, mm	NIR, mm	GIR –F., mm	F. Irr. Schedules Depth, mm	GIR –drip irri., mm	GIR by drip, in lit.	Drip system (#) operating time Hr:Min
10	39.72	0.10	0.33	13.11	0.10	13.01	21.68	(*) 80	14.46	7.23	1:50
11	41.08	0.00	0.33	13.56	0.00	13.56	22.59		15.06	7.53	1:60
12	42.21	1.97	0.41	17.19	1.97	15.21	25.36	75	16.91	12.68	3:10
13	46.06	0.12	0.42	19.34	0.12	19.22	32.04		21.36	17.09	4:15
14	47.75	0.78	0.42	20.06	0.78	19.28	32.13	75	21.42	17.14	4:15
15	49.49	0.00	0.51	25.17	0.00	25.17	41.95		27.97	22.37	5:40
16	52.34	0.63	0.73	38.21	0.63	37.58	62.63	80	41.75	33.40	8:20
17	53.09	0.41	0.73	38.76	0.41	38.35	63.91	80	42.61	34.09	8:30
18	54.94	0.00	0.73	40.10	0.00	40.10	66.84		44.56	35.65	9:00
19	55.38	2.50	0.73	40.43	2.50	37.93	63.21	80	42.14	33.71	8:30
20	56.80	4.00	0.69	38.95	4.00	34.95	58.25		38.84	31.07	7:50
21	58.43	6.00	0.42	24.54	6.00	18.54	30.90	75	20.60	16.48	4:10
22	59.91	11.00	0.42	25.16	11.00	14.17	23.61		15.74	12.59	3:10
Total irrigation requirement by furrow irrigation							545.11	545			

Note: ET_0: Reference Evapotranspiration; Kc: Crop Coefficent; ETc : Actual Evapotranspiration; ER: Effective Rainfall; NIR: Net irrigation requirement; GIR: Gross irrigation requirement; F: Furrow;

*: pre sowing irrigation;

16 mm diameter inline lateral with 4 l hr^{-1} per emitter discharge capacity

developmental stage, in which increase in number of leaves, elongation of all the leaves, stem elongation took place. This was completed within 70 days after transplanting (Fig.1). The mid stage begins with topping and desuckering and continued up to physiological maturity of the leaves. In this stage, expansion of leaves to its full size, increase in weight of the leaves, changes in colour of the leaves. It ends with ripening of the bottom leaves, at 120 days after transplanting. The late season stage continues up to harvest of the leaves and duration upto150 days after transplanting (Fig. 1).

The initial stage of pearl millet was from sowing to tiller development was completed within 15 days after sowing. The growing stage, in which the elongation of the panicle takes place, completed within 50 days after sowing. The mid stage as indicated by the development of dark layer at the bottom of the grain and ended by 75 days after sowing. The late season stage was continued up to harvest of the crop at 90 days after sowing (Fig. 2).

Crop evapotranspiration

The average reference evapotranspiration during various growth stages of bidi tobacco crop period was varied from 2.61 to 3.71 mm day^{-1}. Highest were noted during crop initial stage and continuously decreases in up to mid season stage and increases in end season stage (Table 1). This is mainly due to higher temperatures in initial and comparatively lower temperatures in mid stage. The average actual evapotranspiration during various growth stages of bidi tobacco crop period was varied from 1.4 to 2.68 mm day^{-1}. Lowest were noted during end season. From initial stage onwards ETc was continuously increased up to mid season stage and was decreased in end season stage (Table 1). ETc increased over time due to canopy development as observed in the initial stage; attained a nearly constant rate in the mid-stage and declined in the late stage. Increasing trend of crop evapotranspiration in the mid-stages can be attributed to more crop water demand owing to full canopy development in addition to evaporative demand. However, in the late stage, though there is not much variation in the atmospheric demand, the transpiration rate decreased due to decrease in physiological activity of plants.

The average reference evapotranspiration during various growth stages of summer pearl millet varied from 5.02 to 7.73 mm day^{-1}. Lowest were noted during crop initial stage and continuously increases towards end season (Table 2). The average actual evapotranspiration of pearl millet during the various growth stages varied from 1.7 to 5.31 mm day^{-1}. Lowest were noted during initial stage which increased continuously up to mid season stage and decreased thereafter in the end season stage (Table 2). Increasing trend of crop evapotranspiration in the mid-stages can be attributed to more crop water demand owing to full canopy development in addition to increasing evaporative demand.

Crop coefficients

The average crop co-efficient (Kc) during various growth stages of bidi tobacco varied from 0.42 to 0.86 (Table 1). During the initial stage, Kc value was 0.43, in the mid stage it was 0.85 and during late stage it was 0.44 (Fig. 1). The average crop coefficient during various growth stages of summer pearl millet varied from 0.33 to 0.73 (Table.2). During the initial stage, the average Kc value was 0.33, in the mid stage it was 0.73 and late stage it was 0.42 (Fig. 2).

Irrigation schedules

The weekly net irrigation requirement for bidi tobacco was maximum 23.64 mm in 44^{th} week (Table 3). By furrow irrigation it is scheduled in 8 irrigations with irrigation depth ranging from 50 mm to 75 mm at different intervals (Table 3). A 75 mm depth of transplanting irrigation may be provided. By drip irrigation, the requirement was upto 21 l $week^{-1}$. For supplying these requirement by using drip irrigation (16 mm diameter inline lateral with 4 l hr^{-1} per emitter discharge), it is scheduled in every week with operating time of ranging up to 5:15 hrs duration in a week (Table 3).

The weekly net irrigation requirement for pearl millet crop varied from 13.01 to 40.1 mm (Table 4). These weekly requirements were scheduled by furrow and drip irrigations. By furrow irrigation it is scheduled in 7 irrigations with irrigation depths 75 to 80 mm in different intervals (Table 4). A 75 mm of depth of pre sowing irrigation may be provided. For drip irrigation, the requirement ranging from 7.23 to 35.65 l $week^{-1}$. For supplying these requirement by using drip irrigation (16 mm diameter inline lateral with 4 l hr^{-1} per emitter discharge), it is scheduled in every week with operating time of ranging from 1:50 to 9:00 hrs duration in a week (Table 4).

CONCLUSION

The duration of crop growth stages and respective crop coefficients for various growth stages of bidi tobacco and pearl millet crops determined in the study will be useful to estimate crop water requirements and further developing optimum irrigation schedules for achieving higher water productivity. The optimum irrigation schedules for tobacco and pearl millet crops with different irrigation methods developed in this study will be directly useful for farmers achieving higher productivity. The procedure evolved for developing crop coefficients and developing optimum irrigation schedules with different irrigations methods can also be applied for other crops.

REFERENCES

Allen R.G., Pereira L.S., Raes D. and Smithl M. (1998). Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements. *FAO Irri. Drain. Paper,* 56: FAO, Rome, Italy.

Doorenbos J. and Pruitt W. O. (1977). Crop water requirement. *Irri. Drain. Paper, No.*24 (revised), FAO, Rome, Italy.

Gorantiwar, S.D., Meshram, D.T. and Mitta, H.K. (2011). Water requirement of pomegranate (*Punica granatun* L.) for Ahmedanagar district of Maharastra State, India. *J. Agrometeorol.*, Vol. 13(2):119-122.

Kashyap P.S. and Panda R.K. (2001). Evaluation of evapotranspiration estimation methods and development of crop-coefficients for potato crop in a sub-humid region. *Agri. Water Mgmt.,* 50(1): 9–25

Khandelwal, M.K., Shekh, M.K., Pandey Vyas and Zaman, M.S. (1999). Secetion of appropriate method for computation of potential evapotranspiratio and assessment of rainwater harvesting potential for middle Gujarat. *J. Agrometeorol.*, Vol.1 (2): 163- 166.

Khandelwal, M.K. and Pandey Vyas. (2008). Comparison of PET computed by various methods in different agro climatic stations of Gujarat state. *J. Agrometeorol.,* Vol.10(2): 439-443.

Pandey Vyas, Patel, V.J., Vadodariya, R.P., Patel, H.R., and Shekh, A.M. (2008). Irrigation water requirement and production potentials of major crops over Narmada canal command area in Gujarat. *J. Agrometeorol.*, Vol.10(2):314-320.

Rao, B.K. and Rajput, T.B.S. (2008). Rainfall effectiveness for different crops in canal command areas. *J. Agrometeorol.*, Vol.10(2): 328-332.

Sahoo, D.C., Madhu, M. and Khola, O.P.S. (2009). Estimation of evapotranspiration and crop co-efficient of carrot (*Daucus carota*) for water management using weighing lysimeter. *Indian J. Agri. Sci.,* 79 (12): 968–71

Sikka A.K., Madhu M. and Tripathi K.P. (2001). Comparison of different methods of estimating evapotranspiration in the Nilgiris, South India. *Indian J. Soil Conser.,* 29(3): 213–19.

Received :July 2012 ; Accepted : August 2012