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COMPARATIVE STUDY ON WATER AND HEAT UNIT REQUIREMENT OF FINGER MILLET (*ELEUSINE CORACANA* G.) IN DIFFERENT AGROCLIMATIC REGIONS

1. Finger millet (*Eleusine coracana* Gaertn), also known as Ragi, is an important millet crop and major source of food in many parts of dry farming region in India. As such, it is grown in dry farming region where annual rainfall ranges between 400 mm to 1000 mm. The crop is extensively grown in Karnataka, Tamil Nadu, Andhra Pradesh, Orissa, Bihar, Gujarat, Maharashtra, Uttar Pradesh and Himachal Pradesh, contributing nearly 60% of the total crop production. The crop is grown over an area of about 1.7 million hectare with annual production of about 2.3 million tonnes in the country. The average yield of the crop is 1329 kg/ha (SAI, 2003).

Agrometeorological conditions cause wide fluctuations in growth, development and yield of finger millet crop. Venkataraman *et al.* (1986) studied evapotranspiration of kharif ragi under no moisture stress

conditions during day and night. Ganesan *et al.* (1988) studied the influence of selected weather parameters on biomass production in ragi. Ganesan and Ahobala Rao (1989) found that the duration to flowering in the case of ragi is positively correlated with average temperatures and average evaporation. Kashyapi and Dubey (1996) have studied water requirement of wheat in different agroclimatic regions. Kashyapi and Das (1999), Sengupta *et al.* (2003) have also studied water and heat unit requirement in selected wheat growing zones.

2. In this study, the data on finger millet crop for three different agroclimatic locations, *i.e.*, Anakapalle (1993-1994) (Andhra Pradesh), Bangalore (1983-1985) (Karnataka) and Bhubaneswar (1987-1989) (Orissa) have been utilized. Anakapalle (17° 38' N, 83° 01' E) and Bangalore (13° 00' N, 77° 37' E) represent semiarid agroclimatic region whereas Bhubaneswar (20° 15' N, 85° 52' E) represents dry sub-humid agroclimatic region. The crop was grown during kharif season. The normal rainfall during the crop growing season at Anakapalle, Bangalore and Bhubaneswar is 470 mm, 455 mm and 875 mm respectively. The evapotranspiration (ET), crop yield and other agrometeorological data have been

TABLE 1
Agrometeorological parameters and crop yield of finger millet at Anakapalle, Bangalore and Bhubaneswar

Station	Year	Crop variety	Crop duration (Weeks)	Crop yield (Kg/ha)	ET* (mm)	WUE* (Kg/ha/mm)	Heat units (degree days)	HUE* (Kg/ha / degree days)
Anakapalle	1993	Gouthami	13	2130	300	7.10	1650	1.29
	1994	Gouthami	13	1254	295	4.25	1646	0.76
	Mean	Gouthami	13	1692	297	5.67	1648	1.03
Bangalore	1983	Indal-5	14	1740	314	5.54	1340	1.30
	1984	Indal-5	14	1361	327	4.16	1251	1.09
	1985	Indal-5	14	2012	323	6.23	1260	1.60
	Mean	Indal-5	14	1704	321	5.31	1284	1.33
Bhubaneswar	1987	A-123	13	2367	275	8.61	1762	1.34
	1988	A-123	13	2958	287	10.30	1730	1.71
	1989	A-123	13	2959	280	10.57	1582	1.87
	Mean	A-123	13	2761	281	9.83	1691	1.64

* ET – Evapotranspiration, * WUE – Water use efficiency, * HUE – Heat use efficiency

TABLE 2
Water requirement (ET, percent ET and weekly ET) of finger millet at different phases at Anakapalle, Bangalore and Bhubaneswar

Station	Vegetative			Flowering			Grain Development			Maturity		
	ET* (mm)	ET (%)	Weekly ET (mm)	ET (mm)	ET (%)	Weekly ET (mm)	ET (mm)	ET (%)	Weekly ET (mm)	ET (mm)	ET (%)	Weekly ET (mm)
Anakapalle	132	44.4	22	67	22.5	33.5	49.5	16.6	24.7	49	16.5	16.3
Bangalore	122	37.9	20.3	99	30.8	33	71.7	22.3	23.9	28.7	8.9	14.3
Bhubneswar	126.3	45	21.1	64.9	23.1	32.5	53.3	19	26.7	36	12.8	12
Mean	126.7	42.4	21.1	77	25.5	33	58.2	19.3	25.1	37.9	12.7	14.2

* ET - Evapotranspiration

obtained from the records of India Meteorological Department. The ET data was measured through gravimetric lysimeter located in the crop field, whereas data on meteorological parameters was recorded at the agrometeorological observatory located near the crop field. With regard to water need of the crop, the life span of ragi crop has been divided into four important growth stages, viz., vegetative (up to 6 weeks after sowing (WAS), flowering (7-9 WAS), grain development (10-12 WAS), and maturity (13-14 WAS). The weekly potential evapotranspiration (PET) has been calculated using Penmann's modified formulae (Doorenboss and Pruitt, 1977). In this paper, consumptive use of water (ET), water

use efficiency (WUE), heat units or growing degree days (GDD), heat use efficiency (HUE) and crop coefficient (Kc) for different growth stages of the crop have been computed and discussed. Crop coefficient (Kc) is defined as the ratio of actual evapotranspiration to the potential evapotranspiration and calculated by using following equation;

$$Kc = ET / PET \quad (1)$$

Growing degree days (GDD) or heat units is an index used in relating crop growth to air temperature

TABLE 3
Growing degree days (HU, HU percent, and weekly HU) of finger millet crop at various phenophases at Anakapalle, Bangalore and Bhubaneswar

Station	Vegetative			Flowering			Grain Development			Maturity		
	HU * (degree days)	HU (%)	Weekly HU	HU * (degree days)	HU (%)	Weekly HU	HU * (degree days)	HU (%)	Weekly HU	HU * (degree days)	HU (%)	Weekly HU
Anakapalle	792	48.0	132	274	16.6	137	258	15.7	129	324	19.7	108
Bangalore	552	43.0	92	291	22.7	97	261	20.3	87	180	14.0	90
Bhubaneswar	804	47.5	134	260	15.4	130	270	16.0	135	357	21.1	119
Mean	716	46.2	119.3	275	18.2	121.3	263	17.3	117	287	18.3	105.7

* HU – Heat units

(Vittum *et al.*, 1965) and computed using the following formula:

$$GDD = \sum_{i=1}^n [(T_{\max} + T_{\min})/2] - T_b \quad (2)$$

T_b is the base / threshold temperature below which no crop growth occurs. In the present study, $T_b = 10^\circ$ C has been used (Ganesan *et al.*, 1988).

3. Agrometeorological parameters and crop yield of finger millet at Anakapalle, Bangalore and Bhubaneswar are shown in Table 1. The average yield of finger millet obtained was found to be maximum at Bhubaneswar, *i.e.*, nearly 2760 kg/ha followed by Bangalore and Anakapalle. The crop consumed maximum amount of water consumptive use of water (ET), *i.e.*, nearly 320 mm at Bangalore, followed by Anakapalle and Bhubaneswar. The ratio of crop yield to evapotranspiration, known as water use efficiency (WUE), was found to be maximum, *i.e.*, nearly 9.8 kg/ha/mm at Bhubaneswar, followed by Anakapalle and Bangalore. Though, the consumptive use of water is maximum at Bangalore, the WUE is maximum at Bhubaneswar. It clearly indicates that WUE does not depend only on the total amount of water consumed by the crop but also highlight the importance of its distribution during the various growth stages. Similar results have been obtained with other cereal crops (Verma and Das, 2004). Phasewise water requirement of finger millet is given in Table 2. During vegetative stage, the average water consumed was nearly 42 % and average weekly ET rate was found to be nearly 21mm. The maximum amount of water, *i.e.*, nearly 45 % was consumed at Bhubaneswar and maximum weekly ET rate, *i.e.*, nearly 22 mm has been observed at Anakapalle. During flowering stage, the average water consumed was nearly 25 % and average weekly ET rate

was found to be nearly 33 mm. The maximum amount of water, *i.e.*, nearly 31 % was consumed at Bangalore and maximum weekly ET rate, *i.e.*, nearly 33 mm has been observed at Anakapalle. During grain development stage, the average water consumed was nearly 19 % and average weekly ET rate was found to be nearly 25 mm. The maximum amount of water, *i.e.*, nearly 22 % was consumed at Bangalore and maximum weekly ET rate, *i.e.*, nearly 27 mm has been observed at Bhubaneswar. During maturity stage, the average water consumed was nearly 13 % and average weekly ET rate was found to be nearly 14 mm. The maximum amount of water, *i.e.*, nearly 17 % was consumed at Anakapalle and maximum weekly ET rate, *i.e.*, nearly 16 mm has been observed at Anakapalle. It may be noted that the average weekly ET rates are highest during flowering stage followed by grain development, vegetative and maturity stage. In all stages, except grain development stage, average weekly ET rates were found to be higher at Anakapalle than other locations.

4. The total heat unit (HU) requirement or growing degree days (GDD) for finger millet is given in Table 1. Maximum HU requirement, *i.e.*, nearly 1690 degree-days was found at Bhubaneswar, followed by Anakapalle and Bangalore. The number of heat units required to produce unit amount of grain yield, defined as Heat unit efficiency (HUE), is also given in Table 1. The highest average HUE (1.64 kg/ha/degree days) was observed at Bhubaneswar, followed by Bangalore and Anakapalle.

Phasewise growing degree days are given in Table 3. It may be seen that heat unit requirement in different, growth stages except during flowering, is comparatively higher at Bhubaneswar than other locations. On an average, the crop required nearly 716, 275, 263 and 287 degree-days during vegetative, flowering, grain

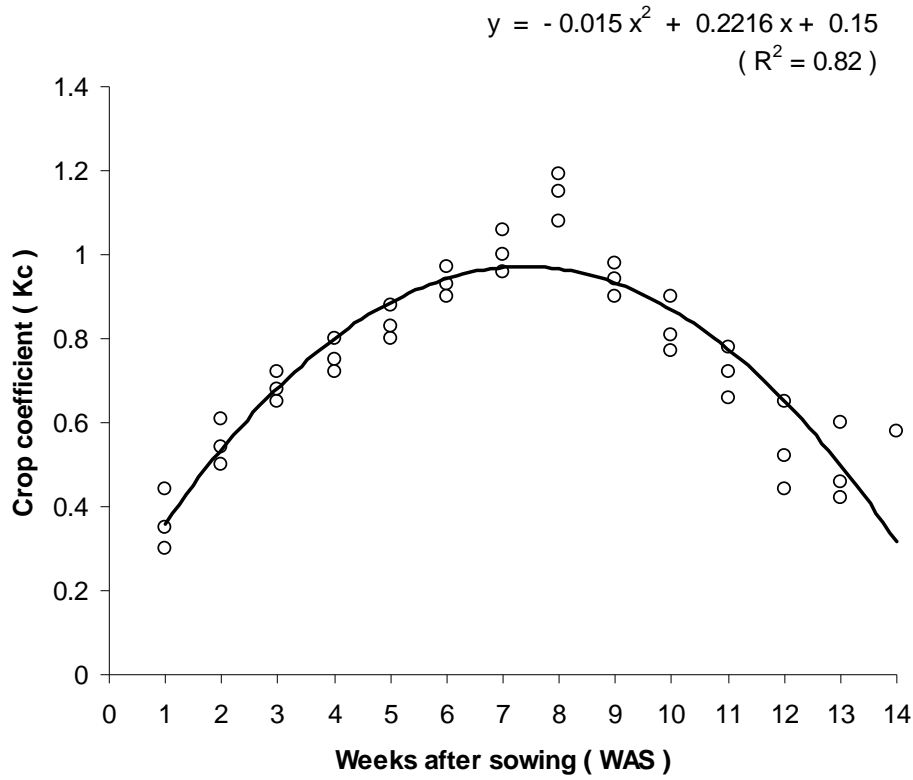


Fig. 1. Variation in crop coefficient (Kc) of finger millet with time (WAS)

TABLE 4

Crop coefficient (Kc) in different growth stages of finger millet at Anakapalle, Bangalore and Bhubaneswar

Station	Crop coefficient (Kc)			
	Vegetative	Flowering	Grain development	Maturity
Anakapalle	0.44 – 0.90	1.05 – 1.15	0.96 – 0.79	0.77 – 0.42
Bangalore	0.30 – 0.93	1.05 – 0.98	0.95 – 0.65	0.60 – 0.58
Bhubaneswar	0.33 – 0.95	1.04 – 1.10	0.97 – 0.79	0.66 – 0.46
Mean	0.36 – 0.93	1.04 – 1.08	0.96 – 0.74	0.67 – 0.49

development and maturity stage respectively. It means that heat unit requirement is maximum during vegetative stage (*i.e.*, nearly 46 %) and nearly equal (*i.e.*, 18 %), in other growth stages. Weekly heat units, in all growth stages, were found to be higher and nearly equal at

Anakapalle and Bhubaneswar compared to Bangalore. On an average, weekly heat unit requirement was found to be nearly 120, 120, 117 and 105 degree-days during vegetative, flowering, grain development and maturity stage respectively.

5. The Crop coefficient values for different growth stages of finger millet are given in Table 4. On an average, crop coefficient (Kc) values varied in the range 0.36 – 0.93, 1.04 – 1.08, 0.96 – 0.74 and 0.67 – 0.49 during vegetative, flowering, grain development and maturity stage respectively. Variation in crop coefficient (Kc) with weeks after sowing (WAS) of finger millet is shown in Fig. 1. It may be seen that Kc values are low during the initial stage of the growth and follow the rising trend (0.36 to 0.93) during vegetative stage. Kc values attain the peak (1.04 to 1.08) during the flowering stage. It means the climatic demand for water is high during flowering stage, when the crop is in good state of health. Thereafter, Kc values decline gradually during grain development (0.96 to 0.74) and maturity stage (0.67 to 0.49). The trend observed in Kc values of finger millet during different stages of growth were compared for those given by Doorenboss and Kasam (1979), agreed fairly well. When Kc values were fitted to time, utilizing the combined data of Anakapalle, Bangalore and Bhubaneswar, the following non linear relationship is obtained;

$$Kc = -0.015 (WAS)^2 + 0.2216 (WAS) + 0.15$$

$$(R^2 = 0.82)$$

Using this equation, it is possible to estimate crop coefficient (Kc) values, at any time (WAS) or stage during crop growth. Das *et al.* (1995), Verma *et al.* (2004) have also observed such non relationship of crop coefficient.

6. (i) The crop yield was found to be maximum at Bhubaneswar (2761 kg/ha), followed by Bangalore and Anakapalle .

(ii) Maximum amount of water (nearly 320 mm) was consumed at Bangalore, followed by Anakapalle and Bhubaneswar.

(iii) The WUE was found to be maximum (9.8 kg/ha/mm) at Bhubaneswar, followed by Anakapalle and Bangalore. It was also observed that WUE does not depend only on the total amount of water consumed by the crop but also highlight the importance of its distribution during the various growth stages.

(iv) On an average, the crop consumed nearly 42%, 25%, 19% and 13% of water during vegetative, flowering, grain development and maturity stage respectively. However, the average weekly ET rates were found to be highest during flowering stage (nearly 33 mm).

(v) Heat unit requirement was found to be maximum at Bhubaneswar (1690 degree-days), followed by Anakapalle and Bangalore. Also, heat unit requirement is highest during vegetative stage (nearly 46%) and nearly equal (18%), in other growth stages.

(vi) The HUE was found to be maximum (1.64 kg/ha/degree days) at Bhubaneswar, followed by Bangalore and Anakapalle.

(vii) Average crop coefficient (Kc) values at Anakapalle, Bangalore and Bhubaneswar varied in the range 0.36 – 0.93, 1.04 – 1.08, 0.96 – 0.74 and 0.67 – 0.49 during vegetative, flowering, grain development and maturity stage respectively. The crop coefficient values attained the peak during the flowering stage.

Acknowledgements

The authors express their sincere thanks to Shri M. G. Ghanekar and DFR staff for their assistance in computation, analysis and typing of this paper.

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