

## A study on the consumptive use of water by kharif rice at Canning (West Bengal)

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**सारांश** — खरीफ ऋतु के दौरान, 1977 से 1992 तक के आँकड़ों के आधार पर, कानिंग (पश्चिम बंगाल) में खरीफ चावल की फसल के लिए, माध्य साप्ताहिक वाष्पोत्सर्जन और फसल की विभिन्न अवस्थाओं में होने वाले कुल वाष्पीय ह्रास पर इसके योगदान का परिकलन किया गया है। वाष्पोत्सर्जन-वाष्पीकरण अनुपात (ई० टी०/ई० पी०) और फसल-गुणाओं के मान पुष्पन अवस्था के दौरान अधिकतम पाए गए। वाष्पोत्सर्जन-वाष्पीकरण अनुपात और प्रत्यारोपण के बाद दिनों की संख्या के बीच एक प्रकार का संबंध स्थापित किया गया जिसकी मदद से, वाष्पीकरण और प्रत्यारोपण की तिथियों की जानकारी के आधार पर, वाष्पोत्सर्जन का पता लगाया जा सकता है। वाष्पोत्सर्जन और कुल लघु तरंगीय विकिरण के मध्य अनुपात, जो कि ऊर्जा संतुलन घटकों के संयुक्त प्रभाव को प्रदर्शित करता है, पुष्पन अवस्था के दौरान अधिकतम मान ग्रहण कर लेता है। फसल की बढ़वार की अवस्थाओं की पहचान के लिए, विभिन्न वाष्पोत्सर्जन चारों भिन्न-भिन्न ऊर्जा योगिक-गुणाओं में श्रेष्ठतर प्राचल प्रतीत होता है। खरीफ चावल की जल-उपयोग क्षमता में उल्लेखनीय वार्षिक परिवर्तन दृष्टिगोचर होते हैं।

**ABSTRACT.** Based on the data for the period from 1977 to 1992 during the kharif season, mean weekly evapotranspiration (ET) and its contribution for different phases to total evaporative loss have been worked out for kharif rice at Canning. The evapotranspiration- evaporation ratio (ET/EP) and crop-coefficient ( $K_c$ ) have been found to attain peak values during the flowering stage. A relationship between ET/EP and number of days from transplanting has been developed and this relationship helps in determining ET from a knowledge of EP and date of transplanting. Ratio of evapotranspiration to total shortwave radiation (ET/ $R_s$ ), which represents the combined effect of energy balance components, also reaches its peak value during the flowering stage. Among the four different energy summation indices, the potential evapotranspiration seems to be a better parameter for identification of growth stages of the crop. Water use efficiency of kharif rice shows significant year-to-year variations.

**Key words** — Consumptive use, Transplanting, Water use efficiency, Heat unit, Senescence, Evapotranspiration (ET), Crop coefficient.

### 1. Introduction

Rice (*Oryza sativa*) is a staple food for a large section of Indian population. Paddy is a water loving tropical crop grown in areas where annual rainfall is 1000 mm or more. Though a hydro-phyte plant, paddy is grown under varied climatic conditions from semi-arid to humid if water is provided at some of its critical phases.

Evaporation from soil and plant surfaces, commonly known as evapotranspiration, is a primary component of the energy exchange function and determines the production potential of crop species and the distribution of natural vegetation. It is highly correlated with net productivity.

Accurate measurement or estimation of evapotranspiration for paddy aids in management of irrigation facilities; developing sound practices by agronomists; determining the water balance of rainfed rice and achieving irrigation or water conservation goals to meet the crop's water requirement and classifying rice environments where genetic

and agronomic technology may be transferable etc.

Studies on evapotranspiration (ET) of rice in India have attracted the notice of Indian agro-scientists for quite some time. For instance, Pande and Mitra (1971) observed total ET loss at Kharagpur (West Bengal) as 669 mm in rabi season. Ghildyal and Tomar (1976) found that wet land rice at Pantnagar transpires nearly 990 mm of water during its growth cycle. Based on lysimetric observations, Subbarao *et al.* (1976) studied evapotranspiration (ET) of paddy in relation to pan evaporation (EP) at Nellore and Canning. They observed that reduction in crop transpiration is more pronounced at Nellore than at Canning. Tomar and O'Toole (1979) were of the view that evapotranspiration is a complex process affected primarily by climatic conditions. They found that the ET ranged from 4-7 mm/day in wet land rice fields. Transpiration rate during the course of day was found more responsive to vapour pressure deficit and wind speed than solar radiation by O'Toole and Tomar (1982). Maske and Rathore

TABLE 1  
Agrometeorological statistics for kharif paddy

Year	Variety	Date of transplanting	Duration (days)	Consumptive ET use (mm)	Evaporation (EP) (mm)	Potential ET (mm)	Seasonal rainfall (mm)	Shortwave radiation (mm)
1977	Mut. I	28-7-77	75	534.7	331.6	411.2	677.4	578.2
1979	Mut. I	20-7-79	62	395.3	312.5	409.5	396.3	660.6
1980	CSR-4	19-8-80	78	395.5	265.0	366.9	485.6	627.4
1982	CSR-4	20-7-82	82	455.0	348.3	403.0	495.3	671.6
1983	CSR-6	23-8-83	75	345.4	276.6	339.9	553.2	569.6
1984	CSR-4	14-8-84	95	511.3	346.4	465.2	587.6	812.3
1986	CSR-4	13-8-86	75	451.7	416.4	488.2	1369.8	937.0
1990	CSR-4	21-7-90	94	439.7	364.3	441.1	990.9	642.8
1991	CSR-4	29-8-91	100	313.0	289.4	424.8	654.9	721.4
1992	CSR-4	30-6-92	130	539.5	502.3	465.0	1401.6	930.0
Mean			87	438.1	345.3	421.5	761.3	715.0
CV (%)			20.9	16.7	19.6	10.3	45.6	17.8
SD			18.1	73.0	67.5	43.5	347.1	127.5

TABLE 2  
Mean weekly consumptive water use (mm) and crop-coefficient ( $K_c$ ) at different stages of crop growth

Transplanting	Tillering	Flag leaf	Panicle emergence	Flowering	Fruiting	Maturity
Water use						
33.6 (15.4)	37.2 (17.0)	40.1 (9.3)	42.0 (9.6)	46.3 (21.2)	35.1 (16.0)	25.3 (11.5)
Crop coefficient						
0.80	0.92	0.95	1.05	1.15	1.05	0.90

N.B. Figures in the bracket indicate phasewise percentage water use of total water use.

(1990) using ET data of three different agroclimatic zones, viz., Ranchi, Bhubaneswar and Varanasi concluded that upland paddy cannot successfully be grown in areas receiving weekly rainfall less than 35 mm for a minimum period of 15 weeks. Jenson and Rahman (1987) formulated a model to calculate evaporation and transpiration for wet land paddy. For the entire crop season, they estimated that evaporation contributed to nearly 1/3 of ET. Singh and Prasad (1991) studied water use pattern and yield response of rice under different levels of irrigation at Pusa (Bihar). For selected districts in West Bengal, Mandal and Kar (1993) determined transpiration rates of rice in relation to potential ET.

The great need to improve water management requires a good quantitative estimate of the consumption of water or evapotranspiration (ET). Wetland rice is the main water user in many

developing countries. Quantitative understanding of the water dynamics of the wet land rice system, in particular with respect of evaporation and transpiration, usually the main components of the rice field water balance would help evaluating suitability of locations suitable for a particular paddy specie.

In the present study, such an attempt has been made for Canning (West Bengal).

## 2. Materials and method

The study utilizes data for 1977 to 1992 crop seasons for paddy at Canning (22.15°N, 80.40°E) in West Bengal. The soil around Canning is mostly silty clay loam with field capacity 34.3%, bulk density 1.56 g/cm<sup>3</sup> and permanent wilting point 17.5%. The evapotranspiration (ET) was measured through volumetric lysimeter located in the crop field and

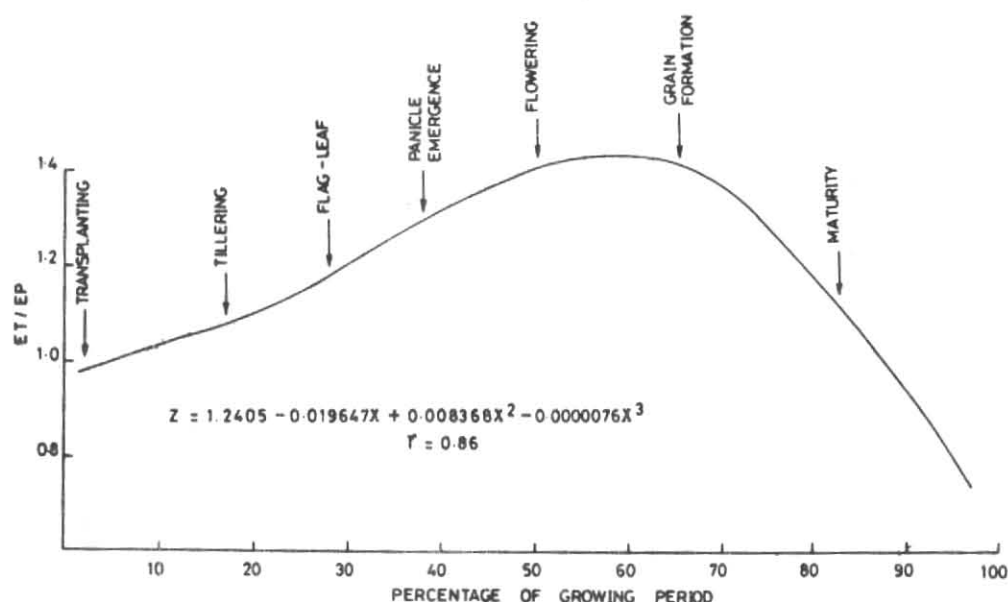


Fig. 1. Relationship between ET/EP and days after transplanting

maintained by India Meteorological Department. This was used to determine consumptive water use by the paddy plant and the water use efficiency. The evaporation (EP) values refer to standard US open pan evaporimeter, while the potential evapotranspiration (PET) was calculated from usual meteorological elements by modified Penman's method. The EP, hours of sunshine and meteorological data needed for computing PET were obtained from the Agromet Observatory located near the crop field. The incoming solar radiation ( $R_s$ ) was calculated indirectly from number of sunshine hours, using Angstrom standard formula,

$$R_s = (a + b n/N) R_A \quad (1)$$

where  $R_A$  is the theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere,  $n$  is the actual duration of sunshine hours,  $N$  is the maximum possible duration of sunshine and  $a$  and  $b$  are constants. The sunshine hours were recorded by Campbell-Stroke Solarimeter.

The rice seed yield figures pertain to the lysimetric tank and represent the economic yield of the crop obtained by dividing seed production in the tank by the area of the tank. From the daily weather data, weekly totals of various agrometeorological parameters from the date of sowing to physiological maturity were computed. Details about variety used, dates of sowing and harvest etc. are given in Table 1.

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Concept of heat unit (HU) which is based on the assumption that the plants have particular range of temperature requirement for their growth, has been used in the study. The HU has been computed by subtracting the base temperature of  $10^\circ\text{C}$  from the mean daily temperature. A factor of 0.45 was used (Meek *et al.* 1984) to convert incoming radiation values into photo-synthetically active radiation. The crop co-efficient ( $K_c$ ), has been estimated using the relationship :

$$K_c = \text{ET/PET} \quad (2)$$

### 3. Results and discussion

#### 3.1. Water use and crop co-efficient

The total growing season, rainfall and total water use during kharif season are given in Table 1. Year-to-year variability in consumptive use of water is generally observed, which probably stem from the basic variability inherent in monsoon rainfall. It is seen that total rainfall generally exceeded total ET during the growing period. This indicates that excess water was available to the crop over and above its evapotranspiration demands. The lowest water, *i.e.*, 315 mm was consumed in 1991 whereas in 1992, the crop used maximum amount of water, *i.e.*, 540 mm. The mean water used by paddy at Canning was 430 mm. Ignoring the crop specie, it appears possible to raise paddy in 87 days at Canning. The mean consumptive use is about 438 mm which is marginally more than evapotranspirative demand. However, the rainfall during the crop season is

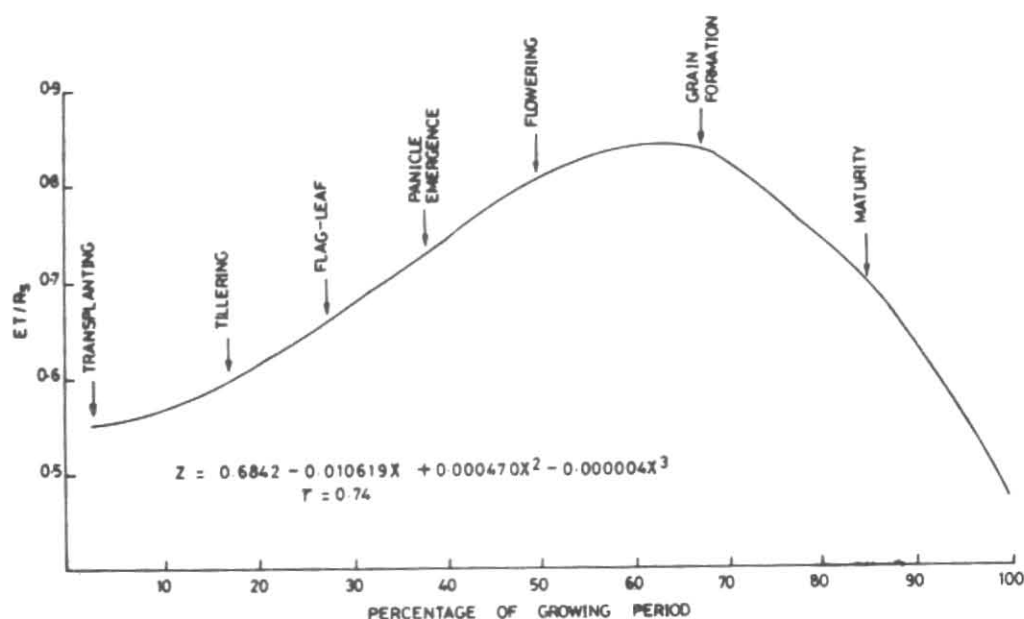


Fig. 2. March of  $ET/R_s$  against growing period

nearly 50% more than the water used. The variability in consumptive use is also low, *i.e.*, 16.7%.

Analysis of mean weekly ET during different phases of growth (Table 2) and its contribution to total water use revealed that during transplanting the weekly water used is 34 mm, *i.e.*, about 15% of seasonal water use. The weekly water used during flowering is found to be maximum compared to other phases and is 21% of the total ET.

The values of  $K_c$  in different phases of growth are also shown in Table 2. It is seen that, the  $K_c$  gradually increases from transplanting as the plant development progresses. The peak value of  $K_c$ , 1.2 is attained during flowering stage. Effect of plant senescence is clearly seen by gradual decline in the  $K_c$  values during the maturity stage when the value falls below 0.7.

### 3.2. $ET/EP$ ratio in relation to crop development

A generalised relationship between  $ET/EP$  and growth rate is shown in Fig. 1. The  $ET/EP$  ratio assume a value of 1.0 right from the beginning of the crop growth phase. This is because water during transplanting is non-limiting. During the active growth phase of the crop, particularly between flag leaf to fruiting when the crop is completely covering the ground, the ratio exceeds 1.2. The pattern is typically a single peaked one, occurring during flowering with a maximum value of about 1.4. The sharp decline after flowering is obviously associated

with grain filling and maturity stages during which the leaves undergo rapid senescence. The mean  $ET/EP$  ratio is found to be 1.3 which generally agreed with values given by Tomar and O'Toole (1979) for different rice varieties in various countries.  $ET/EP$  ratio does not, as a rule, vary much from  $ET/PET$ , since  $EP$  and  $PET$  both represent evaporative power of atmosphere. As such, considering  $ET/EP$  as a crop co-efficient,  $K_c$ , it is seen that this ratio agrees well with the range of 1.05-1.20 crop coefficient given by Hargreaves *et al.* (1985).

An attempt was also made to find mathematical relationship between days after planting ( $X$ ) and  $ET/EP$  ( $Z$ ) by fitting a polynomial. In determining the coefficients only those terms which were statistically significant at 5% level were retained in the equation. The result obtained is given below:

$$Z = 1.2 - 19.7 \cdot 10^{-3}X + 8.4 \cdot 10^{-3}X^2 - 7.6 \cdot 10^{-6}X^3 \quad (3)$$

The correlation coefficient  $r = 0.86$  was quite high and significant and indicates that from  $EP$ , the  $ET$  data for paddy at Canning could be estimated.

### 3.3. $ET-R_s$ relationship

The incoming solar radiation ( $R_s$ ) alongwith wind and humidity contributes significantly towards the total evaporation of the atmosphere. The ratio  $ET/R_s$  reflects the combined effect of the energy balance components. The weekly variation of  $ET/R_s$  ratio is shown in Fig. 2.

TABLE 3

Statistics of energy unit indices

Indices	Mean	SD ( $\sigma$ )	CV (%)
<b>Transplanting to flowering</b>			
HU ( $^{\circ}$ C)	1069.1	128.7	12.0
EP (mm)	244.9	41.8	17.1
PET (mm)	310.5	30.8	9.9
PAR (mm)	210.1	22.1	12.9
<b>Transplantation to maturity</b>			
HU ( $^{\circ}$ C)	1490.9	210.7	14.1
EP (mm)	345.3	67.5	19.6
PET (mm)	421.5	43.5	10.3
PAR (mm)	314.1	55.0	17.6

ET/ $R_s$  increases gradually as the vegetative cover develops. Maximum ET/ $R_s$  ratio of 0.85 is attained at flowering stage and decreases almost linearly later because of the crop senescence. For sandy clay loam, Namken *et al.* (1968) found that maximum value of this ratio was 0.73 for cotton.

The rapid decline of ET/ $R_s$  ratio, after attaining peak, indicates reduced transpiration rates due to lack of available water in the root zone which limits plant evaporation. The maximum ET/ $R_s$  ratio was observed when the plant had attained maximum height.

Increased leaf area and concurrent increase in percentage of the ground shaded by the plant canopy probably explains much of the increase of the ratio during that time. Subsequently, though the plant height remained unaltered, rapid senescence leads to reduced plant evaporation and hence reduced ET/ $R_s$  ratio

#### 3.4. Energy summation indices

The rate of crop development can be considered as a function of the energy receipts and temperature conditions prevailing in a season. Sastry and Chakravarthy (1982) showed that energy summation indices representing radiation, thermal units and pan and potential transpiration could be used for identification of phenological events and maturity dates in crops. In the study, the value of the four indices namely heat units (HU), pan evaporation (EP), potential evapotranspiration (PET) and photosynthetically active radiation (PAR) were accumulated from transplantation to flowering and from transplantation to maturity separately and coefficient of variation (CV) and standard deviation

TABLE 4

Water use efficiency

Year	Grain yield (kg/ha)	Water use (mm)	WUE (kg/ha/mm)
1977	3613	534.7	6.76
1979	3870	395.3	9.79
1980	4300	395.5	10.87
1982	2640	455.0	5.80
1983	2410	345.4	6.97
1984	2500	511.3	4.89
1986	2540	451.7	5.62
1990	3262	439.7	7.41
1991	2150	313.0	6.87
1992	2400	539.2	4.45

( $\sigma$ ) were computed. As may be seen from Table 3, among the four indices, PET has the lowest CV equal to 9.9% and 10.3% for the period transplantation to flowering and transplantation to maturity respectively. The HU and radiation based units gave relatively higher CV for both the stages of crop growth. CV was found to be highest in case of pan evaporation during both the stages. Of all the indices, PET proved to be the best parameter for both the stages for identification of various phases of the crop. The kharif paddy growing season at Canning corresponds to the south-west monsoon season during which EP shows high year-to-year variability due to variations in sky conditions.

#### 3.5. Water use efficiency

When the actual evaporation falls short of its potential, the actual yield should also be less than the maximum. However, the relationship between the evapotranspiration and yield in the field may or may not be linear as has been found between transpiration and dry matter production in experiments. This is partly because the fraction of the evaporation that does not contribute to the plant growth varies throughout the crop life-cycle. The ratio of crop yield to evapotranspiration known as Water Use Efficiency (WUE), serves as a very useful tool in crop and variety selection for maximum yield per unit of water consumed. The WUE is thus given by

$$WUE = Y/ET \quad (4)$$

where, Y = Yield of crop

ET = Cumulative evapotranspiration during crop growth period.

If yields were completely independent of ET, any factor which causes an increase of yield or a decrease of ET, would have a favourable effect on WUE. If yields were proportional to ET, water use efficiency would be constant. Actually numerator or denominator in the above equation are not independent of each other. Both are influenced independently or differentially, by crop management and environmental factors. The numerator  $Y$  is also greatly dependent on moisture regime, the more water available to the crop, the higher the yields. A greater water supply will, however also increase the denominator ET. The WUE of paddy for different years are shown in Table 4. Corresponding yield and ET are also presented in the table.

It is seen that the WUE varies from year-to-year with a minimum 4.5 kg/ha/mm in 1992 to a maximum 10.87 kg/ha/mm in 1980. In 1991, despite poor yield of 2150 kg/ha. WUE is somehow large (*i.e.*, 6.9 kg/ha/mm), because of low cumulative ET of 310 mm. The wide variations in WUE may be attributed to the plant species and varying environments in different years.

#### 4. Conclusions

The following conclusions could be drawn :

- (i) The weekly water use and crop coefficient during flowering are found to be maximum compared to other phases.
- (ii) The pattern of ET/EP ratio is typically a single-peaked one occurring during flowering. This ratio is closely related to growth rate.
- (iii)  $ET/R_s$  ratio increases gradually as the vegetative cover develops, reaching maximum during flowering stage.
- (iv) PET seems to be a better parameter for identification of phenological events.

- (v) Water use efficiency revealed a high degree of year-to-year variability.

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