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# A study on parameters controlling water requirement of rice (*Oryza sativa* L.) at various phenophases in different agroclimatic zones

A. KASHYAPI, H. P. DAS, A. P. HAGE and A. A. KALE

*Agricultural Meteorology Division, India Meteorological Department, Pune, India*

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**e mail : kashyapi_a@yahoo.co.in**

**सार** – इस शोध पत्र में धान की फसल और अन्य फसलों में पानी की आवश्यकता को नियंत्रित करने वाले प्राचलों के आँकड़े एकत्र किए गए और उनका आठ विभिन्न वाष्पोत्सर्जन केंद्रों के गत पाँच वर्षों के उपलब्ध आँकड़ों का ग्यारह महत्वपूर्ण अवस्थाओं का आकलन तथा औसत मानों का विश्लेषण किया गया। इस अध्ययन से यह पता चला है कि धान उगाने वाले विभिन्न वाष्पोत्सर्जन केंद्रों में धान की फसल के लिए पानी की कुल आवश्यकता – माँग 411.3 से 688.7 मि. मी. तक रही। अधिकांश केन्द्रों में दौजी अवस्था से सक्रिय दौजी अवस्था के दौरान चरम वाष्पोत्सर्जन रिकार्ड किया गया जिसके परणिाम–स्वरूप फसल के लिए कुल पानी की 27 से 38 प्रतिशत तक की आवश्यकता पूरी हुई। अधिकांश केन्द्रों में फसल की बढ़ोतरी की विभिन्न अवस्थाओं में मौसमी वर्षा वाष्पोत्सर्जन की आवश्यकता को पूरा करने के लिए पर्याप्त पाई गई। तथापि, कुछ केन्द्रों में सुनिश्चित सिंचाई की सुविधा उपलब्ध होने के कारण अच्छी पैदावार रिकार्ड की गई। अध्ययन किए गए विभिन्न केन्द्रों के औसत फसल गुणांक (के. सी.) मानों में (फसल की बढ़ोतरी के दौरान) 0.77 से 1.13 तक के परिवर्तन का पता चला है। अधिकांश केन्द्रों में सक्रिय दौजी अवस्था में फसल गुणांक (के. सी.) मान अधिकतम रहे। कुछ केन्द्रों में बढ़ोतरी की छह और उससे अधिक अवस्थाओं में फसल गुणांक (के. सी.) मान एक से भी अधिक रहा। धान की उपज 1839 कि. ग्रा. / हैक्टेयर से 5892 कि.ग्रा./ हैक्टेयर तक पाई गई। इसके अलावा, फसल के उत्पादन में 15.074 से 51.684 कि.ग्रा/ हैक्टेयर / दिन तक का बड़ा अंतर पाया गया। विभिन्न केन्द्रों में फसल की पानी की उपयोगिता की क्षमता 3.68 से 10.71 कि. ग्रा. / हैक्टेयर / मि. मि. तक पाई गई।

**ABSTRACT.** The parameters controlling water requirement of rice crop and other crop related data were collected and computed at eleven critical phenophases, from eight different ET – stations, for latest available five years and the mean values were analyzed. The study revealed that the total water requirement – demand for rice crop in different rice growing ET – stations varied from 411.3 to 688.7 mm of water. In most of the stations peak ET was recorded during tillering to active tillering stages, which contributed 27 – 38 per cent of the total water need of the crop. The seasonal rainfall in most of the stations was sufficient to meet the ET requirement at various growth stages. However, few stations recorded high yield due to assured irrigation facility. The average Kc values (throughout the crop growth period) showed variation from 0.77 to 1.13 among different stations studied. For most of the stations Kc values reached their peak mostly at active tillering stage onward. At some stations six or more growth stages recorded Kc values even more than one. Rice yield varied from 1839 kg/ha to 5892 kg/ha. Also, the crop productivity varied widely from 15.074 to 51.684 kg/ha/day. The WUE of the crop in different stations laid between 3.68 to 10.71 kg/ha/mm.

**Key words** – Water requirement, Critical growth stages, ET (Evapotranspiration), Kc (Crop coefficient), Productivity, WUE (Water use efficiency), Transplanting, Lag phase, Panicle initiation.

## 1. Introduction

Rice is the most important cereal crop in India. It is a heat loving but semi – aquatic plant and hence the crop water requirement is very high. Tiller formation is stimulated when shallow flooding is allowed, which leads to large diurnal variations of soil and water temperatures (Robertson, 1976). The crop can be grown in pre-kharif, kharif as well as in rabi seasons. During kharif season it is the major crop grown under rainfed condition and the crop is raised utilizing the monsoon rain mainly. In the country the crop is grown in most of the states; mainly in Andhra Pradesh, West Bengal, Bihar, Uttar Pradesh, Madhya Pradesh, Orissa, Tamil Nadu, Assam, Karnataka, Kerala,

**TABLE 1**

**Yield (kg/ha), productivity (kg/ha/day) and water use efficiency (WUE in kg/ha/mm) of rice indifferent agroclimatic zones**

| Parameters | ET – stations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canning | Bikramganj | Varanasi | Ludhiana | Ranchi | Shymakhunta | Annamalai Nagar | Pattambi |
| Yield (kg/ha) | 1839 | 5166 | 4407 | 5892 | 1896 | 4350 | 3790 | 3425 |
| Productivity (kg/ha/day) | 15.074 | 34.440 | 34.701 | 51.684 | 17.236 | 27.358 | 24.140 | 28.306 |
| Total Actual ET | 499.1 | 540.3 | 411.3 | 688.7 | 423.3 | 506.8 | 671.1 | 492.7 |
| WUE (kg/ha/mm) | 3.68 | 9.56 | 10.71 | 8.56 | 4.48 | 8.58 | 5.65 | 6.95 |
| Data studied (5 years) | 1999 to 2003 | 2000 to 2004 | 1998 to 2000, 2002, 2003 | 2000 to 2004 | 1995, 1996, 1999 to 2001 | 1997 to 2001 | 1997 to 1999, 2002 | 1999, 2000, 2002 to 2004 |

Maharashtra and Punjab. As per estimate of Directorate of Rice Development, Patna, rice crop (during both kharif and rabi seasons) is grown in 449.72 lac hectares area and its production is 894.76 lac tonnes.

The crop duration varies from 110 to around 155 days. The critical growth stages for the crop are identified as germination, nursery seedling, transplanting, tillering, active tillering, lag phase, panicle initiation, flowering, grain formation, grain maturity and harvesting. These eleven growth stages are found critical in their specific demand for water. The duration of each of the growth stages varies according to the variety, soil type and weather parameters prevalent in that locality. However, the crop is very much sensitive to water deficiency at flowering and grain formation stages. During kharif season also, standing water from end of tillering to grain maturity is ideal for obtaining higher yield.

In India, the rainfall amount and its distribution in most parts excluding north-west India, is favourable for raising kharif rice. The optimum well distributed rainfall during almost 4 months span of the crop is around 100 to 120 cm. Profile stored moisture also plays crucial role towards fulfillment of crop water requirement. The important parameters controlling the water requirement of rice are actual evapotranspiration (ET), potential evapotranspiration (PET), soil moisture, crop coefficient (Kc) and water use efficiency (WUE) as reported earlier for wheat crop (Kashyapi and Dubey 1996). The present work is undertaken to study the parameters controlling water requirement of rice crop at different critical growth stages in different rice growing ET - stations in different agroclimatic zones. 8 ET - stations were selected where rice was grown in recent years from 6 different agroclimatic zones, for this study.

## 2. Methodology

### 2.1. *Selection of rice growing zones*

ET - stations where rice grows in recent years from different agroclimatic zones, *viz*., lower Gangetic plains, middle Gangetic plains, trans Gangetic plains, eastern plateau and hill region, east coast plains and hill region and western plains and ghat region (Planning Commission, Govt. of India, 1989 ) were selected for the study. The selected ET - stations were: Canning (22° 15´ N, 88° 40´ E), Bikramganj (25° 10´ N, 84° 15´ E), Varanasi (25° 18´ N, 83° 01´ E), Ludhiana (30° 56´ N, 75° 52´ E), Ranchi (23°17´N, 85°19´E) , Shymakhunta (21° 56´ N, 86°46´ E), Annamalai Nagar (11° 24´ N, 79° 41´ E) and Pattambi (10° 48´ N, 76° 12´E). The study period (years) for different stations is presented in Table 1. Soil types varied from heavy clay, clay, clay loam, sandy loam, red loam to reddish brown laterite.

### 2.2. *Data collection*

#### 2.2.1. *Crop data*

The crop data were collected for latest five years from the ET - stations where rice grows. The mean for the five years were computed. The rice varieties mostly grown are presented in Fig. 1. The mean date of sowing, mean date of harvesting and mean span of the crop (in days), respectively, in each of the station studied are provided

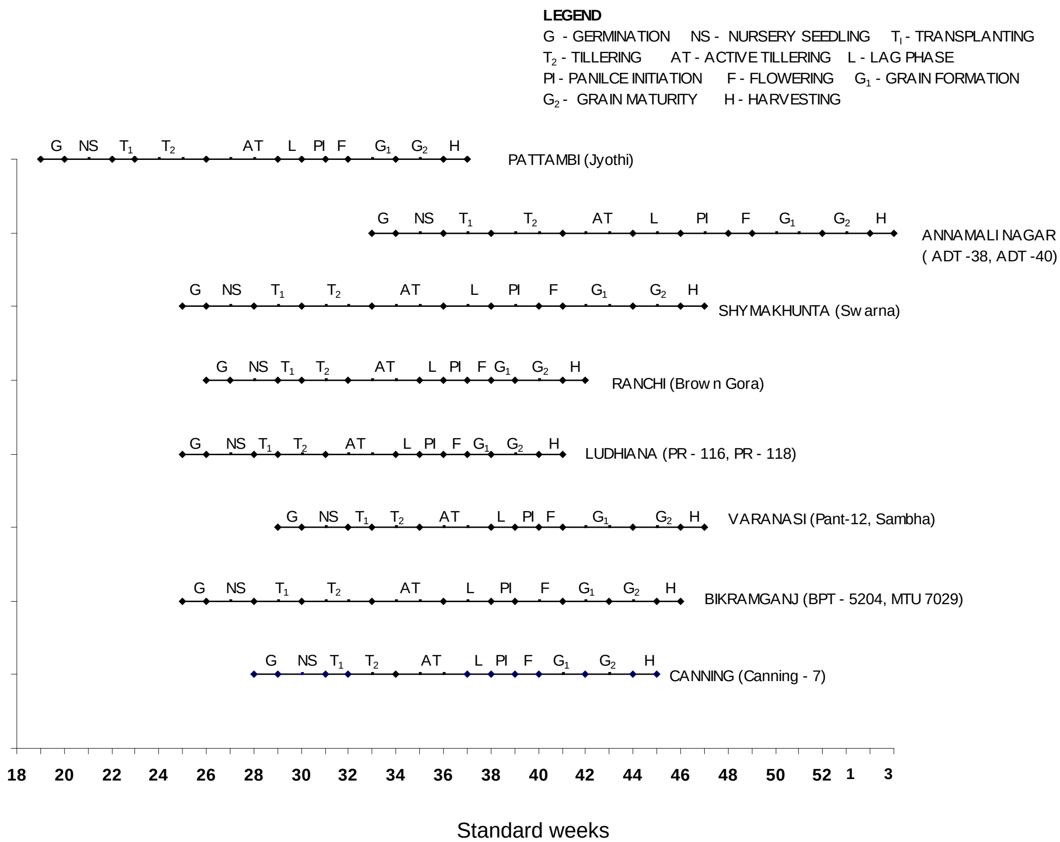



**Fig. 1**. Duration-wise growth stages of rice crop (varieties within parenthesis) at different ET - stations

within parenthesis: Canning (12 Jul, 10 Nov and 122 days), Bikramganj (21 Jun, 17 Nov and 150 days), Varanasi (19 Jul, 22 Nov and 127 days), Ludhiana (20 Jun, 11 Oct and 114 days), Ranchi (1 Jul, 18 Oct and 110 days), Shyamkhunta (20 Jun, 25 Nov and 159 days), Annamalai Nagar (16 Aug, 19 Jan and 157 days) and Pattambi (13 May, 10 Sep and 121 days). The mean crop yield (in kg/ha) and mean crop productivity (in kg/ha/day) for five years are presented in Table 1.

2.2.2. *Data on parameters controlling water requirement of rice crop*

The parameters studied were rainfall, actual evapotranspiration, potential evapotranspiration and water use efficiency. Eleven critical growth stages were identified covering full span of the crop, which were: germination (G), nursery seedling (NS), transplanting (T1), tillering (T2), active tillering (AT), lag phase (L), panicle initiation (PI), flowering (F), grain formation (G1), grain maturity (G2) and harvesting (H). Different growth stages of rice crop at different ET - stations are presented in Fig. 1, along with predominant variety within parenthesis.

Rainfall data were collected from all the stations studied for the five years and the mean values are presented, growth stage-wise in Table 2 for each of the stations.

For computation of weekly PET, modified Penman method was used. Mean daily PET values for 52 weeks using weekly meteorological normal were obtained (Khambete and Biswas 1992) and growth stage-wise PET were derived and are presented in Table 2.

Actual evapotranspiration (ET) is directly measured with use of lysimeter (both volumetric and gravimetric). For rice crop available soil moisture is limited by depth and density of root system. At the same time in lysimeter, both the factors are limited alongwith advection (due to limitation of lysimeter depth). Considering these inherent constraints the lysimeter data from each of the stations were collected for five years. For each year growth stage-wise cumulation was made to obtain ET at different phenophases and the mean ET values were obtained and are presented in Table 2.

**TABLE 2**

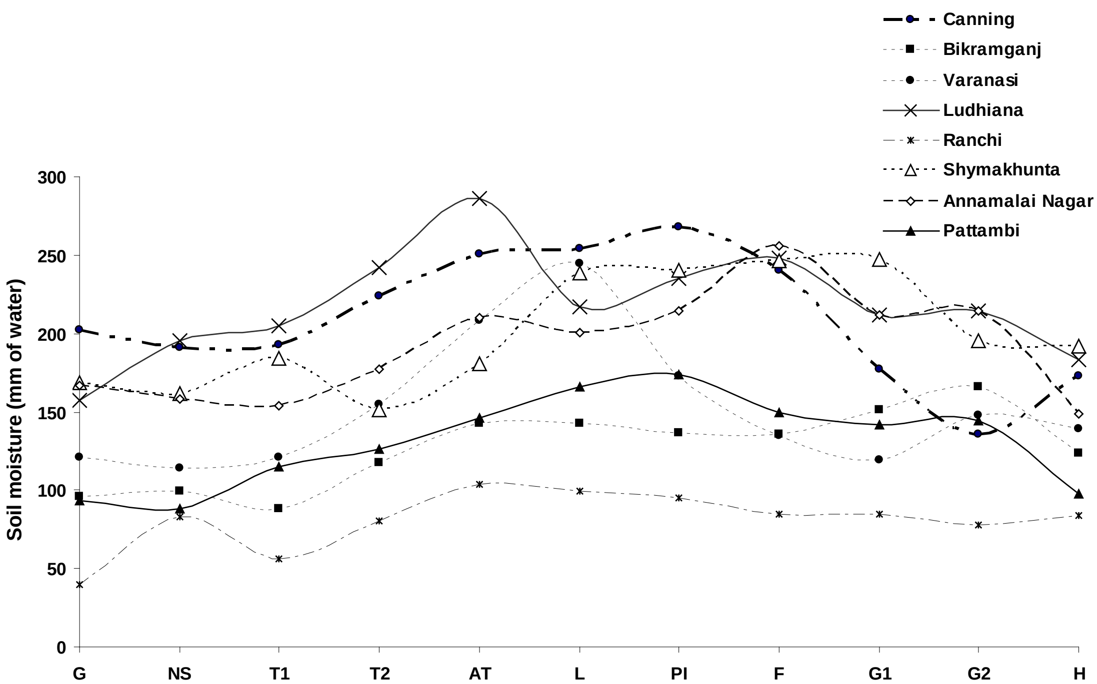
**Mean rainfall – P, potential evapotranspiration-PET and actual evapotranspiration – ET (all in mm of water) at various growth stages in different agroclimatic zones during rice growing season**

| Crop growth stages | ET - stations | | | | | |
|---|---|---|---|---|---|---|
| | Canning | | | Bikramganj | | |
| | P | PET | ET | P | PET | ET |
| Germination | 84.5 | 32.3 | 27.6 | 44.5 | 39.4 | 24.3 |
| Nursery seedling | 187.8 | 63.0 | 50.9 | 116.0 | 92.1 | 58.8 |
| Transplanting | 64.5 | 34.6 | 28.3 | 42.0 | 51.2 | 29.2 |
| Tillering | 154.7 | 83.2 | 79.1 | 115.8 | 109.9 | 83.4 |
| Active tillering | 203.4 | 90.0 | 95.7 | 153.1 | 99.6 | 91.7 |
| Lag phase | 88.9 | 32.3 | 34.7 | 73.6 | 61.8 | 57.0 |
| Panicle initiation | 55.9 | 32.3 | 36.7 | 30.0 | 41.4 | 36.7 |
| Flowering | 32.2 | 36.0 | 36.6 | 14.2 | 44.7 | 39.3 |
| Grain formation | 151.1 | 70.7 | 53.1 | 8.4 | 51.7 | 50.5 |
| Grain maturity | 51.0 | 62.7 | 36.0 | 7.6 | 43.3 | 46.3 |
| Harvesting | 0.8 | 28.1 | 20.4 | 0.0 | 28.8 | 23.1 |
| Total | 1074.8 | 565.2 | 499.1 | 605.2 | 663.9 | 540.3 |

| Crop growth stages | ET - stations | | | | | |
|---|---|---|---|---|---|---|
| | Varanasi | | | Ludhiana | | |
| | P | PET | ET | P | PET | ET |
| Germination | 72.1 | 37.7 | 22.9 | 20.9 | 40.0 | 29.9 |
| Nursery seedling | 89.5 | 72.5 | 41.3 | 101.9 | 88.2 | 81.8 |
| Transplanting | 115.0 | 30.5 | 18.4 | 49.8 | 41.6 | 40.6 |
| Tillering | 164.9 | 80.6 | 62.6 | 42.8 | 88.9 | 102.3 |
| Active tillering | 211.5 | 91.4 | 95.0 | 114.4 | 107.9 | 147.0 |
| Lag phase | 45.1 | 28.6 | 35.1 | 29.0 | 49.4 | 51.0 |
| Panicle initiation | 15.0 | 29.8 | 25.8 | 46.8 | 46.0 | 51.4 |
| Flowering | 12.5 | 34.1 | 23.0 | 23.8 | 46.3 | 54.6 |
| Grain formation | 19.6 | 58.6 | 35.0 | 40.5 | 56.4 | 57.0 |
| Grain maturity | 1.8 | 45.8 | 33.8 | 6.7 | 47.8 | 48.8 |
| Harvesting | 7.6 | 26.5 | 18.4 | 2.1 | 27.9 | 24.3 |
| Total | 754.6 | 536.1 | 411.3 | 478.7 | 610.4 | 688.7 |

| Crop growth stages | ET - stations | | | | | |
|---|---|---|---|---|---|---|
| | Ranchi | | | Shymakhunta | | |
| | P | PET | ET | P | PET | ET |
| Germination | 21.4 | 26.8 | 12.0 | 41.8 | 30.7 | 20.7 |
| Nursery seedling | 218.2 | 65.3 | 60.4 | 168.5 | 81.1 | 52.5 |
| Transplanting | 118.0 | 31.4 | 19.7 | 166.5 | 42.2 | 31.1 |
| Tillering | 200.0 | 58.7 | 52.4 | 275.7 | 96.5 | 58.4 |
| Active tillering | 239.4 | 84.5 | 97.9 | 226.5 | 106.6 | 77.3 |
| Lag phase | 93.2 | 28.7 | 31.5 | 149.5 | 55.7 | 53.3 |
| Panicle initiation | 93.3 | 32.0 | 33.8 | 100.5 | 43.3 | 41.5 |
| Flowering | 75.0 | 29.7 | 28.0 | 24.4 | 46.7 | 46.0 |
| Grain formation | 52.1 | 41.9 | 39.6 | 91.9 | 63.6 | 62.8 |
| Grain maturity | 29.0 | 41.5 | 31.4 | 19.3 | 45.1 | 35.1 |
| Harvesting | 6.8 | 25.9 | 16.6 | 15.5 | 36.5 | 28.1 |
| Total | 1146.4 | 461.4 | 423.3 | 1280.1 | 648.0 | 506.8 |

| Crop growth stages | ET - stations | | | | | |
|---|---|---|---|---|---|---|
| | Annamalai Nagar | | | Pattambi | | |
| | P | PET | ET | P | PET | ET |
| Germination | 49.2 | 40.3 | 33.7 | 62.3 | 46.7 | 31.5 |
| Nursery seedling | 23.7 | 104.3 | 82.6 | 111.8 | 63.4 | 40.3 |
| Transplanting | 10.2 | 64.7 | 49.9 | 135.6 | 30.5 | 25.4 |
| Tillering | 151.7 | 109.5 | 96.7 | 393.0 | 65.2 | 59.7 |
| Active tillering | 263.6 | 105.3 | 110.7 | 237.0 | 81.0 | 85.7 |
| Lag phase | 146.9 | 54.6 | 54.9 | 91.7 | 27.5 | 33.1 |
| Panicle initiation | 186.6 | 36.8 | 39.3 | 93.9 | 28.4 | 35.9 |
| Flowering | 222.4 | 40.6 | 52.0 | 112.1 | 27.6 | 30.0 |
| Grain formation | 95.0 | 61.1 | 64.8 | 194.5 | 57.5 | 59.2 |
| Grain maturity | 1.6 | 54.8 | 58.6 | 107.3 | 66.7 | 69.4 |
| Harvesting | 1.9 | 37.5 | 27.9 | 31.2 | 31.6 | 22.5 |
| Total | 1152.8 | 709.5 | 671.1 | 1570.4 | 526.1 | 492.7 |




LEGEND : G- GERMINATION, NS – NURSERY SEEDLING, T1 – TRANSPLANTING, T2- TILLERING, AT – ACTIVE TILLERING, L- LAG PHASE, PI – PANICLE INITIATION, F- FLOWERING, G1 – GRAIN FORMATION, G2 – GRAIN MATURITY, H- HARVESTING

**Fig. 2**. Soil moisture at various growth stages of rice crop at different ET - stations

In absence of actual soil moisture data at various crop growth stages in different ET stations, field capacity (FC) of the available soil and ET, PET values at various crop growth stages were used to compute soil moisture (SM) at various growth stages of rice crop as given below (Mavi 1994):

$$SM = ET \times FC / PET \qquad (1)$$

The assumptions for equation 1 as suggested by Thornthwaite are that the equation functions between two points: (*i*) SM = 0, when ET = 0 and (*ii*) SM = FC, when ET = PET; in between the equation performs linearly.

The Computed soil moisture (mm) at various growth stages of the crop for different stations is presented in Fig. 2.

The crop coefficient (Kc) for all the five years was obtained by the formula:

$$Kc = ET / PET \qquad (2)$$

The mean Kc values growth stage-wise for each of the stations are presented in Fig.3.

The water use efficiency (WUE) was computed by the formula :

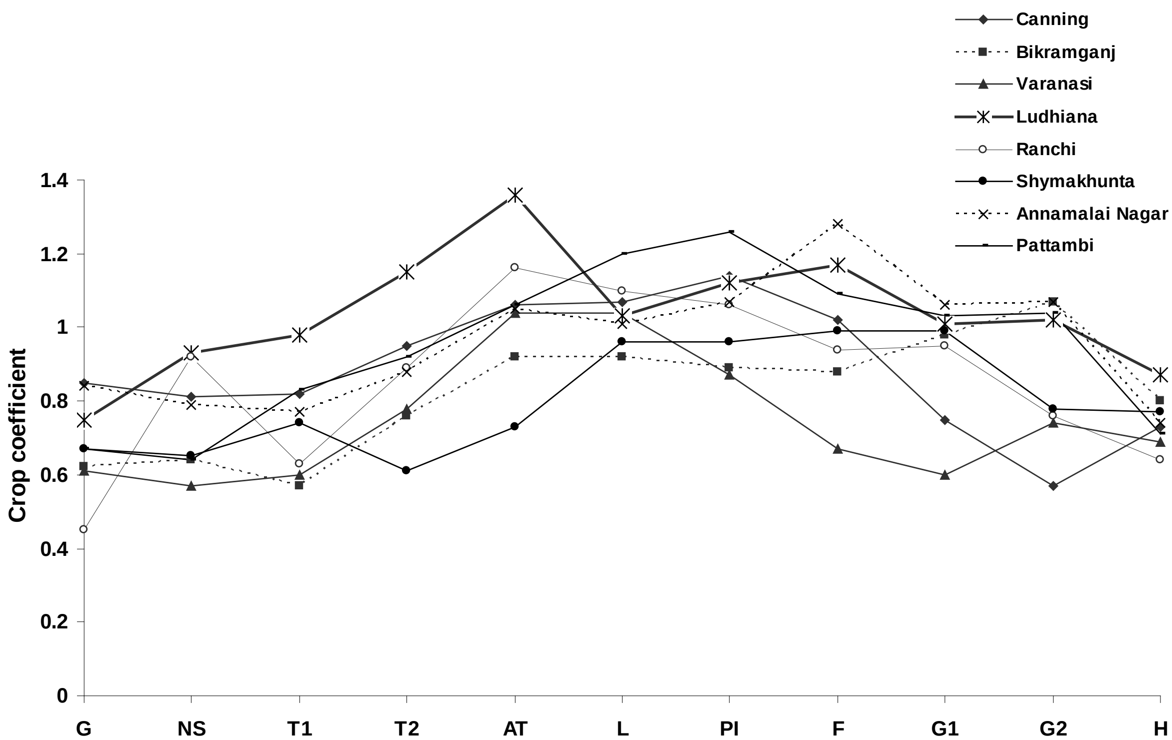
$$WUE = Yield / Total\ ET \qquad (3)$$

For each station, WUE for the five years were obtained and the mean values are presented in Table 1.

## 3. Results and discussion

### 3.1. *Rainfall*

The mean rainfall as presented in Table 2 showed that Pattambi received the highest rainfall (1570.4 mm) and Canning, Ranchi, Shymakhunta, Annamalai Nagar received rainfall of around 1075 mm or more, where the crop was raised as rainfed one. While mainly Ludhiana (where rainfall was less than crop water need of that station) and partially Bikramganj, Varanasi received less rainfall, but crop production was high enough due to




LEGEND : G- GERMINATION, NS – NURSERY SEEDLING, T1 – TRANSPLANTING, T2- TILLERING, AT – ACTIVE TILLERING, L- LAG PHASE, PI –PANICLE INITIATION, F- FLOWERING, G1 – GRAIN FORMATION, G2 – GRAIN MATURITY, H- HARVESTING

**Fig. 3.** Crop coefficient (Kc) at various growth stages of rice crop at different ET - stations

assured irrigation facilities at various critical growth stages of the crop in those areas. Among all the stations studied amount of rainfall received was high mainly during active tillering, tillering stages of crop growth.

### 3.2. *Potential evapotranspiration (PET)*

The PET values of all the stations (Table 2) showed that it varied from 461.4 mm at Ranchi to 709.5 mm at Annamalai Nagar. Among the growth stages of the crop the PET demand was at the peak at tillering to active tillering stages, while secondary peaks were observed at nursery seedling and grain formation stages. The rate of PET was governed by evaporative power of air as determined by radiation, humidity, wind (Mukammal and Bruce 1960) and also by state of soil, its structure, moisture content and colour as varied in different agroclimatic zones (Vitkevich 1968).

### 3.3. *Actual evapotranspiration (ET)*

The ET of rice crop during various growth stages at different ET – stations are presented in Table 2. The ET - demand was the highest at Ludhiana and Annamalai Nagar, while the demand was the lowest at Varanasi and Ranchi. Initially the ET-demand was low at germination and transplanting stages. The demand was high at tillering to active tillering stages followed by nursery seedling and grain formation stages. While low demand was recorded during early growth stage as well as after grain maturity. It is observed that when the ET falls short of PET, the actual yield will also be less than the maximum, though the relationship between ET and yield may not be linear (Chang 1968). In the present study, except Ludhiana, for all the stations rainfall was more than ET. The profile stored moisture along with rainfall was enough to meet ET- demand of the crop at any point of the crop life span (Fig.2). However, if the rainfall and profile stored soil moisture together was insufficient to meet the crop ET – demand, the only alternative remains was to apply irrigation water.

### 3.4. *Soil moisture*

The general pattern of variation in soil moisture as computed at different growth stages are depicted in Fig. 2.Their values increased upto around panicle initiation stage and then decreased gradually upto harvest. The mean soil moisture varied from 81 mm (at Ranchi) to 210 mm (at Canning). Sufficient soil moisture level was maintained during active crop growth stages to support crop growth properly.

### 3.5. *Crop coefficient (Kc)*

Computed Kc values as presented in Fig. 3 showed wide fluctuations among various growth stages as well as among various stations studied. On an average Kc values were the highest at Ludhiana followed by Annamalai Nagar, Pattambi and Ranchi. For all the stations, Kc values were initially low, which reached their peak mostly at active tillering stage onward. For Ludhiana, Annamalai Nagar and Pattambi, 6 or more growth stages showed Kc values more than one, which indicated that ET was more than PET during those growth stages. These Kc values act as a tool for comparing relationship between water and crop yield obtained in different areas (Chang *et al*., 1963). Kakde (1985) and Kashyapi and Dubey (1996) reported that at some advanced plant growth stages under favourable moisture conditions ET rate was even greater than PET. In rice, leaf area index reached its peak mostly at around active tillering stage, which resulted in higher ET rate and as a result Kc values increased at active tillering stage onward.

### 3.6. *Spatial variation in yield, productivity and WUE of rice crop*

The yield, productivity and water use efficiency values for all the stations studied are summarized in Table 1. The yield data varied widely from 1839 kg/ha at Canning to 5892 kg/ha at Ludhiana. In most of the stations, *viz*., Ludhiana, Bikramganj, Varanasi, Shyamakhunta, Annamalai Nagar and Pattambi rice yield was high enough, while at Canning and Ranchi, rice yield was very low. Productivity of the crop in different ET – stations showed almost same pattern as that of yield (showed wide variation from 15.074 to 51.684 kg/ha/day). Productivity at Ludhiana was very high, while it was the lowest at Canning, closely followed by Ranchi. However, WUE was the highest at Varanasi (10.71 kg/ha/mm) followed by that observed at Bikramganj, Shyamakhunta and Ludhiana. WUE was the lowest at Canning (3.68 kg/ha/mm) followed by Ranchi and Annamalai Nagar. It has been noticed that WUE increased with the increase in crop yield (Michael 1990) or decrease in consumptive use of water demand in that station (Kashyapi and Dubey 1996).

## 4. Conclusions

The present study on parameters controlling water requirement of rice crop revealed the following conclusions:

(*i*) The total ET – demand of rice crop for the stations studied, varied from 411.3 to 688.7 mm with peak ET – demand mostly at tillering to active tillering stages (two stages combined to 27-38 percent of the total ET – demand).

(*ii*) The seasonal rainfall was mostly sufficient to meet the crop specific ET- demand at various growth stages of rice. Mainly in Ludhiana (where rainfall was less than total ET- demand) and partially in Bikramganj, Varanasi, crop production was high due to assured irrigation facility.

(*iii*) Soil moisture increased upto panicle initiation stage and then decreased gradually upto harvest.

(*iv*) The average Kc values varied from 0.77 (at Varanasi) to 1.13 (at Ludhiana). Kc values reached their peak mostly at active tillering stage onward. At Ludhiana, Annamalai Nagar and Pattambi, six or more growth stages recorded Kc values more than one.

(*v*) Rice yield varied from 1839 kg/ha at Canning to 5892 kg/ha at Ludhiana and its productivity varied widely from 15.074 to 51.684 kg/ha/day, while WUE varied from 3.68 kg/ha/mm at Canning to 10.71 kg/ha/mm at Varanasi.

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