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Assessment of Water Requirements of Rice Crop: An Innovative Approach

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Abstract: The actual water requirement of rice crop measurement is very susceptible particularly in large paddy fields with high water table and wet climate. In this study an innovative method was applied to measure actual water requirements of rice crop in Nanjing, China. The main reason behind this study was to assess the actual evapo-transpiration (ET) of rice crop in paddy soil at field and laboratory for ET prediction by empirical equations. CROPWAT 8.0 model (Penman-Monteith) and other empirical equations were used to predict the effective evapo-transpiration. Four treatments were applied with three replications both field and at laboratory. During experiments surface water fluctuations were measured by wooden gauge installed at different locations in the field, whereas in the laboratory with iron gauge fixed in each container. The ground water fluctuations were monitored by piezometers installed in field and in laboratory containers. The result reveals that effective evapo-transpiration in field was 484.6mm, while the predicted ET by CROPWAT was 510.3mm. It further reveals that effective evapo-transpiration predicted by Cropwat and Blaney-Criddle methods were 5.04% and 36.6%. The ET predicted by Thornwaite, Hargreaves-Samani and Priestly-Taylor methods were 3.2%, 8.8% and 9.3% less as of the field.

Keywords*:* Effective Evapo-Transpiration; Field; Laboratory; CROPWAT 8.0; Empirical Equations, Rice Crop

1 INTRODUCTION

Rice, the most common staple food crop, it needs sufficient amount of water for its cultivation as compared to other crops. Therefore, it is very important to find its actual water requirement for good yield and more water productivity (Feng *et al.,* 2007). India and china are the maximum rice producing countries of the world; however, its production has been threatened in both countries (Singh *et al.*, 2006). The per capita water resources are decreasing globally; China is currently around 2200m^3/year. This figure is about one-fourth of the world’s average (World Bank, 2000). It is reported that the future yield may also be influenced by the unavailability of irrigation water (Huang *et al.*, 2002).

Monitoring available soil moisture content in the crop root zone may allow in better of water application to meet the crop requirements. Nevertheless, a direct measurement of soil water in the field is wearisome on large scale. The approaches that are accurate require clear better knowledge of soil, its types, available fertility, crop growth stage, variety, planting timings, different weather parameters means exact soil, crop and atmospheric relationship (Annandale *et al.,* 1999). Doorenbos and Pruitt (1984) explain evapo-transpiration is total water depth required to raise the disease free crop throughout the season up to harvesting.

Syuker and Verma (2008), explains that in a growing season there is a consumption of 60 to 80% net radiation that is caused by Evapo-transpiration. Crop growth and yield has a significant influence due to water cycle. Evapo-transpiration helps to improve water productivity, which is going to be critical due to scarcity of water worldwide. Crops weakness tolerance ability depends upon plant factors i.e.; development stages and species etc and it also depends upon soil type, its fertility, ground water table, water logging and surrounding temperature etc. (Tabuchui, 1992; Nishio, 1983; Furuki, 1983; Goor, 1974; Sugimoto, 1971; Yamada, 1968; Murakami, 1968 and Matsushima, 1962). Mostly evapotranspiration is calculated by multiplying the referenced Evapo-transpiration by the Kc (crop coefficient) factor, that depends on ground cover and crop characteristics (Allen *et al.,* 1998). The reference Evapo-transpiration plays an important role for estimating the crop water requirement. Mostly weather data is used for estimation of Evapo-transpiration (Tyagi *et al.,* 2000; Lecina *et al.,* 2003; Shab and Edling, 2000; Lage *et al.*, 2003).

Penman-Monteith process is used to calculate reference evapo-transpiration as described in FAO-56 method, in which meteorological data and Kc is used. Crop coefficient is influenced by structural and

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physiological parameters of the plant. Same (FAO-56) method is used for the calculation of ET and for predication of Kc for different crops in the fields (Tyagi *et al.,* 2000; Shab and Edling, 2000; Lecina *et al.,* 2003 and Lage *et al.,* 2003). Allen *et al.* (2005) predicated Kc and potential ET by FAO-56 method. FAO crop coefficients for different crop development stages of rice given by Allen et al. (1998), for initial stage ranges from 1.10-1.15, for development 1.10-1.50, Mid season 1.10-1.30 and for late season 0.95-1.05. For total period; it ranges from 1.05-1.2. First value uses for high humidity (RHmin > 70%) and low wind velocity (U<5 m/s) while second value uses in little humidity (RHmin < 20%) and heavy wind velocity (U >5m/s). The weather condition of our study area (Nanjing, PR China) is humid and has moderate wind speed. Thus the Kc factor taken for rice crop is 1.1, 1.2 and 1.0 for initial, mid and last stage of crop.

Several methods have been developed worldwide to predict crop water requirements where the FAO has instrumental approach. These methods have limited validity on world level and require calibration on the local level calibrations. Keeping in view the above facts an innovative approach was planned to assess the actual evapo-transpiration in open field with wet climate.

2 MATERIALS AND METHODS

Study Area

This study is based on two different of experiments conducted simultaneously in field and laboratory, at Jampoo experimental farm, Pukou and in the laboratory of Engineering College, Nanjing Agricultural University, Nanjing, China. The distance from field and laboratory is about 12km. Weather of the study area is humid and affected by the East Asia Monsoon. Summer is usually hot, the rainfall happens throughout the year. The mean temperature is about 15.9 °C, slightly below to freezing in January.

Field Experiments

Experiment was designed as Randomized Complete Block Design (RBCD) with three replications. In this experiment four different water depths were tested. Each plot of 15m x 21m size was prepared. Water was applied as per four different watering practices i.e., 5cm, 10cm, 15cm and 20cm with three replications. The rice plants were planted in row to row with the space of 20cm, while the plants were planted 15cm apart from each other. All the inputs i.e., fertilizer and pesticides applications were kept constant except water.

The seed of wuyungen No. 23 rice variety sown in the field as well as in the laboratory. It was sown in the nursery for 48 days that consumes 150mm water depth（30mm for 5 times). As the ratio of nursery and field transplantation was 1/8th, need 18.75mm water depth to grow nursery for each plot. Field preparation took 6 days and 50mm water was applied twice (total 100mm) to make field ready for transplantation (seed grown at nursery was also transplanted at laboratory experiments). Four times fertilizers, pesticides were applied and weeding was also cleared four times from the crop.

Evaporation was measured on daily basis by an evaporation pond. The ridges of the treatments were covered with plastic sheets to assure the stoppage of seepage.

Laboratory Experiment

Twelve containers of 0.9m x 0.9m were bought from the market while the piezometers, drainage valves and gauges for measuring of water depth were installed in those containers. **(Fig. 1).**

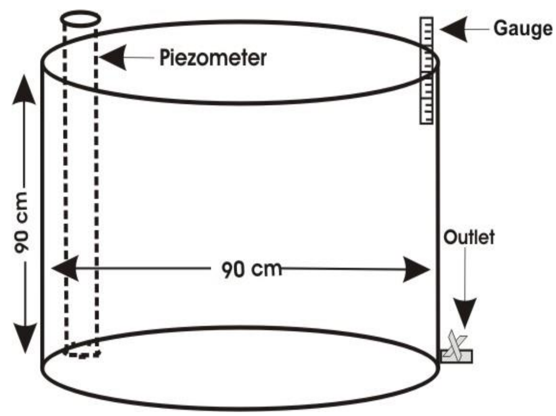

Fig. 1 Schematic layout of the container

Paddy soil (from field experimental plots) was filled up to 70% height in every container and water was applied; each container was applied as per four different watering practices i.e., 5cm, 10cm, 15cm and 20cm with three replications.

For measurement of rate of evapo-transpiration an evaporation pan was used in the laboratory. These measurements were taken on daily basis. Rise and fall of water level in each container was measured every day during whole crop period i.e.; from cultivation up to harvesting. However, the evaporation pan as well as the containers was covered by shelters to protect them from rainfall.

Field and laboratory data collection

Evaporation and Evapo-transpiration data during laboratory experiment was measured five days after transplantation of rice crop in containers and ended three days before harvesting. However, at field only

40days data was used only due to continuous rains and sudden thunder storms, as the plots were open to sky and was no rain protection. First of all crop coefficient Kc was calculated for laboratory evaporation pond and crop cultivated in lab that was calculated as 1.125 for over all transpiration occurred during whole crop duration. While the relationship between evaporation occurred at laboratory for same 40 days was used to get the relationship coefficient and that was observed as 1.1978. Finally, on the basis of total evaporation of 359.6mm at laboratory, the evapotranspiration at field was predicted to be 1.125*1.1978*359.6mm as the actual water requirement of rice crop in paddy field of Nanjing. The difference in evapotranspiration of all depths was found under range of ±1.5%.

The weather data was collected from Nanjing Weather station which includes monthly minimum and maximum temperatures, relative humidity, average speed of wind, rainfall and hours of sunshine. The Kc factor selected for this area 1.1, 1.2 and 1.0 for different crop growth (initial, development and late) stages respectively. The crop growth of rice was divided in to four stages such as, initial, development, maturity and final stage. For each stage Evapo-transpiration was measured and estimated by using CROPWAT8.0.

Water requirement prediction using empirical equations

The empirical equations suggested by Blaney criddle, Hargreaves, Thornthwaite and Preistly and Taylor, were used to predict total crop water requirements and are given bellow:

1) Blaney Criddle Method: This is the simplest method needs only temperature data.

ETo =TP (0.46*Tmean + 8)

Where;

ETo = Reference crop evapotranspiration (mm/day) monthly

T mean = mean temperature (°C) monthly

p = mean percentage of annual daytime hours monthly

2) Hargreaves Method: This process is used for daily or weekly or monthly even for yearly data and requires min., and max., temperature data only.

$ET_o = 0.0023\ (T_{max} - T_{min})\ 0.5\ (T_{mean}+17.8)\ R_a$

Where;

Temperature measured in ºC and

ET in mm/day

The mean temperature is calculated as 0.5 (Tmax+Tmin). Ra is the extra-terrestrial short wave radiation in mm/day. (If Ra is given in MJm-2d-1, then division by 2.45 yields the vale in mm/day). Unless unusual weather patterns exist, the Penman-Monteith and Hargreaves method are in agreement of within 15%

3) Thornthwaite Method: Thornthwaite found that evapotranspiration could be predicted from following equation by using temperature data on monthly basis.

$$ETo = 16\left[\frac{10T}{I}\right]^a$$

where

ETo = Reference crop evapotranspiration (mm/month) Monthly

T = Mean temperature (°C) monthly

a = location dependant coefficient

I = Annual heat index described below:

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.5}$$

and the coefficient is given by

$a = 0.49 + 0.0179\ I - 0.0000771\ I^2 + 0.000000675\ I^3$

4) Priestly-Taylor Method: The Priestley-Taylor equation has the form

$$ETo = \alpha\frac{\Delta}{\Delta+\gamma} + \frac{R_n - G}{\lambda}$$

Where, α = 1.26. ETo is in mm/day, R_n = net radiation, G = soil heat flux in $MJm^{-2}d^{-1}$, l the latent heat of vaporization in $MJkg^{-1}$ and Δ and g are as defined for the Penman equations (kPaºC-1). Shuttleworth (1993) recommends to take α =1.74 for arid climates, α =1.26 in humid climates.

The equations used were based on each combination theory, radiation, and temperature methods. The meteorological data have been used to estimate ET for monthly basis.

3 RESULTS AND DISCUSSION

Results obtained for Evapo-transpiration at field it was 484.6mm excluding 18.78mm for nursery and 100m for land preparation. According to Brouwer and Heibloem (1986) crop water need of paddy rice for entire growth period varies from 450-700mm, while Indiaagronet (2005) explains that stage of crop growth, soil type and climatic conditions are the prime factors for estimation of water requirement.

Bhuiyan, (1992) explains that under local practices in medium to heavy soils of Asia the water requirement is ranging from 500-1200mm and Yoshida, 1981 described that land preparation needs 150 to 250mm, nursery for rice seedlings needed 50mm, in rest period the water requirements was about 500-1200mm at the rate of about 8.5 mm per day for whole season (about 100 days).

On other hand, the Evapo-transpiration determined by CROPWAT shows 5.04% more water required as compared to field observations. However, at Initial stage it showed 8.69% more, at development stage showed 10.17% less water and at its reproductive stage it took 18.2% more water as compare to field. At late Stage it was 3.02% less then field data.

Vu (2005) explains that if atmospheric data is available Kc initial can be predicated properly by FAO-56 method but Kc mid is very sensitive need to be calibrated carefully. The assessment of cumulative etc resulted in approximation variation of about 17% from observed data.

However, the cumulative ET showed maximum difference as 8.69% at initial stage, at development stage showed 3.25% less water and at its reproductive stage it took overall 6.58% and at late stage it took 5.04% more water then field data **(Fig. 2).**

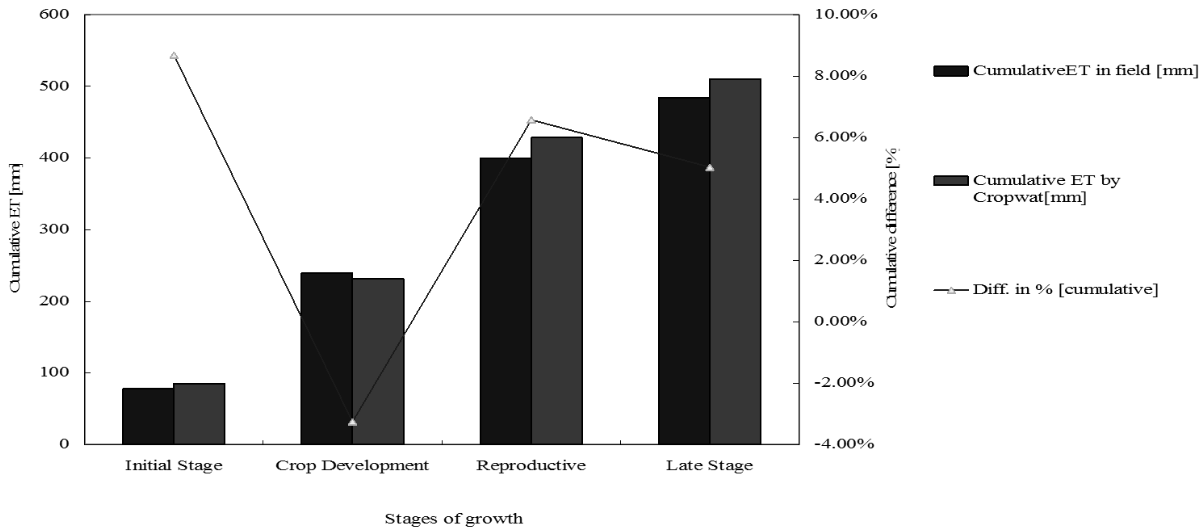

Fig.2 Comparison of cumulative ETo measured in field and calculated by Cropwat.

Results further revealed that Crop water requirements predicted by Blaney-Criddle method was 36.56% more while predicted by Thornwaite, Hargreaves-Samani and Priestly-Taylor methods were 3.2, 8.8 and 9.3% less then as observed in the field **(Fig.3.).**

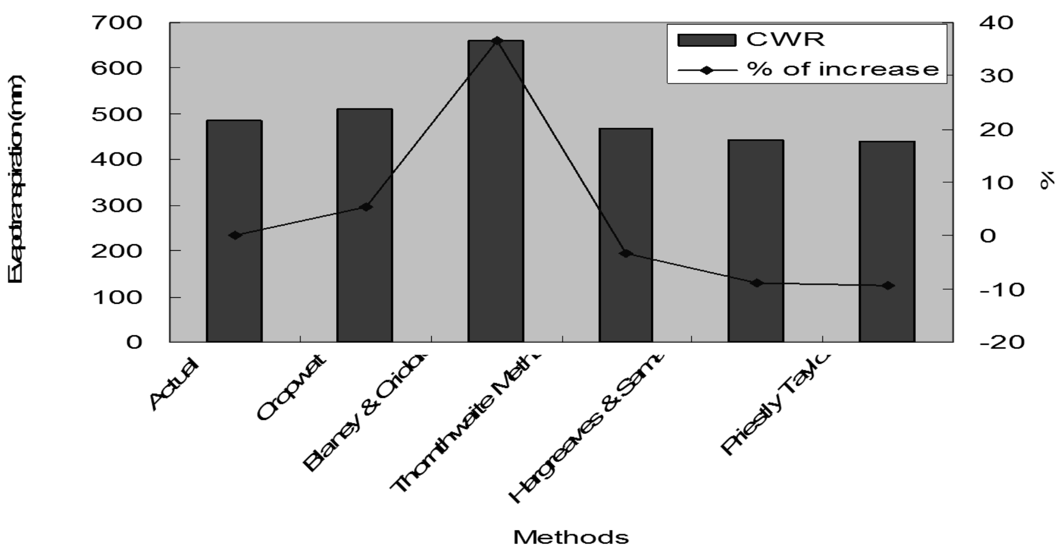

Fig. 3. Measurement and Prediction of Crop Water Requirements

For humid area, Jensen *et al.*, 1990 ranked Penman-Monteith as 1st with an over estimate of 4% while in this case it is 5.04%, those are not too far from each other. While Presistly-Taylor and Thornwaite ranked 5th and 13th with an estimate of 3% and 4% less respectively, whereas, in this case these were -9.3% and -3.2%, which are also under reasonable range of acceptance. However, they ranked Hargreaves-Samani at 10th with

25% and FAO Blaney-Criddle as 9th with 16% over estimation, but in our case these are 8.8% less and 36.6% over estimation in both methods respectively.

4 CONCLUSION

Following conclusion and suggestions were drawn from the present study:

- Effective Evapotranspiration in field was 484.6mm, whilst predicted by CROPWAT 8.0 was 510.3mm.
- Effective evapo-transpiration predicted by CROPWAT 8.0 was 5.04% more as compared to field. That may be considered as almost negligible. Thus Effective Evapo-transpiration of rice crop in Nanjing area accounts for 484.4mm.
- This study suggests that Penman-Montieth, Thornwaite, Hargreaves-Samani, and Priestly-Taylor methods are reasonable and can be used for humid climate area, while Blaney-Criddle over estimates the evapotranspiration.
- This study suggests a continuous four to five years investigation at different locations of Nanjing will also to achieve precise value of water requirement of rice crop.

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