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Determination of Rice Crop Coefficient Using Modified Microlysimeter

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ABSTRACT

Accurate estimates of crop water requirements are needed in the proper design and management of irrigation systems, and to improve irrigation efficiency. These require knowledge of location-specific crop coefficients (K_c) together with climate-specific reference crop evapotranspiration (ET_O). This study aimed to determine K_c values for PSB Rc18 rice variety at each growth stage. A modified microlysimeter setup was used to estimate crop evapotranspiration (ET_C) while local climatic data was used in the FAO-Penman-Monteith equation to determine ET_O. The computed average K_c values during the initial, vegetative, reproductive, and late stages for rice are 1.02, 1.15, 1.14, and 0.78, respectively. These estimated K_c values are very close to locally established and FAO recommended values.

Keywords: crop coefficients, microlysimeter, crop water requirement, rice, CROPWAT, FAO Penman-Monteith

INTRODUCTION

Irrigation plays a very important role in any cropping system. The yield and quality of crops are significantly affected by the sufficiency of water supply and proper irrigation scheduling. With limited water supply in most areas in the country, irrigation water has to be efficiently utilized in a manner that sufficiently corresponds to the water requirements of the crop. The estimation of crop water requirements is the first step in any irrigation management plan and design. Accurate estimates of crop consumptive water use are needed to effectively manage irrigation and improve water use efficiency. The crop water requirements vary substantially throughout the growing period mainly due to variation in crop canopy and climatic conditions (Doorenbos and Pruitt, 1977).

Crop evapotranspiration (*ET*) is the combination of evaporation from wet soil surfaces and transpiration from plants. In a cropped area, they occur simultaneously and there is no easy way to distinguish between the two processes. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (Allen *et al*., 1998). *ET* is an important parameter in predicting the irrigation requirements of crops, estimating runoff from river basins, and in determining the amount of water available from storage reservoirs.

The amount of *ET* is affected by weather parameters, crop characteristics and management, and environmental conditions. *ET* can be expressed in terms of reference crop evapotranspiration (ET_O) or actual crop evapotranspiration (ET_C). ET_O is the *ET* from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground (Allen *et al*., 1998). ET_C, on the other hand, is the ET of a disease-free crop growing in large fields. In cases where measurement of ET_C is not possible, it can be estimated using the ET_O and the crop coefficient.

Crop coefficient (K_C) is the ratio of ET_C to ET_O and it varies with the crop and its development stages. Knowledge of K_C over a variety of crops and for a variety of seasonal conditions can lead to better understanding and management of irrigation water resources, specifically in determining water requirement of the crops according to their growth stage and environmental factors (Triebel, 2005; Shukla *et al*., 2007). Four major factors affect K_C: crop type, climate, soil evaporation, and crop growth stages (Allen *et al*., 1998). Crop characteristics affecting ET_C include albedo, crop height, and leaf stomatal properties. For example, taller full-grown crops often have higher K_C, while lesser stomatal response means lower K_C . ET_O is basically a climatic parameter and K_C values are also affected by climatic parameters, such that, greater wind speed would result in higher K_C. Lastly, crop height, leaf area, and correspondingly ground cover changes as the crop grows, affecting the resulting K_C values.

One of the most reliable methods for determining the K_C values is through lysimetric study. The objective of this study was to establish the crop coefficients of the Philippine Seedboard (PSB) Rc18 rice variety at various crop growth stages using modified microlysimeters. The experiment was conducted during the dry season only as the ensuing wet season experiment was hindered by budgetary and time constraints in the project. Nevertheless, the computed K_C values were then compared with available local literatures and the Food and Agriculture Organization (FAO) established K_C values for rice. While rice yield data were collected and analyzed, these were not discussed in this paper.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in Brgy. Maahas, Los Baños, Laguna (14°10' 48.57" N,121°15' 33.38" E), about 2 km from the National Agrometeorological Station - Philippine Atmospheric, Geophysical and Astronomical Services Administration - University of the Philippines Los Baños - Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (NAS PAGASA-UPLB-PCAARRD), where most of the climatic parameters were obtained. The site is under Type 1 climate with two pronounced seasons, dry from November to April, and wet during the rest of the year. The maximum rain period is from June to September with a mean annual rainfall of 1,942 mm and a mean temperature of 26.7°C. The area is also affected by the microclimatic changes of Laguna Lake and Mount Makiling.

A 32 m x 28 m paddy field (Figure 1) was planted with PSB Rc18 rice variety which generally has a growing period of 123 days. It can grow up to 102 cm, has a long-grain, moderately susceptible to common rice pest, and best suited for irrigated conditions. The experimental site is surrounded by other rice and cornfields. The soil texture is loamy from 0-20 cm depth, and clay loam at 20-50 cm depth. The hardpan is about 36 cm below the top surface of the soil.

Figure 1. Bird's eye view of the experiment site (after harvest).
Source: Google Satellite Image

Water Management

The experiment was undertaken in 120 days during the dry season using low land or flooded rice system. Rice seedlings were transplanted 15 days after seeding with 20 cm × 20 cm spacing. Paddies were regularly irrigated twice a day, once every morning and afternoon. A standing water depth of 3-5 cm was maintained on the early stage (31 days after transplanting), 5-10 cm during the vegetative phase, 8-15 cm from panicle initiation to the flowering stage, and 5-10 on the late phase. Water seepage between adjacent paddies was difficult to prevent, so irrigation water was applied regularly or as required, and the change in water depth each day was recorded and maintained.

Figure 2. Microlysimeter setup at the initial growth stage of rice.

Microlysimeter Setup

A modified lysimeter setup was used to estimate evapotranspiration of rice (Figure 2). The setup included two open-bottom types (percolation tank and seepage tank) which were used to monitor the water depth in the paddy, as well as used in the computation of seepage and percolation losses. No plants were placed inside these tanks. The closed-bottom type was filled with the same soil and leveled up to the same depth of soil in the paddy. This tank was planted with four seedlings of the same variety of rice planted in the whole area and was used for the measurement of evapotranspiration (Figure 2). Water in all the tanks was maintained at a depth of at least 3 cm below the tank rim to at most 2 cm above the water level in the paddy. Change in depth was measured early in the morning (6:00 am to 7:00 am) and in the afternoon (4:00 pm to 6:00 pm) using micrometer hook gage (Figure 3).

Climatic and Agronomic Data Collection

Climatic parameters required in the computation of ET_O such as daily sunshine hours, air temperature, relative humidity, and wind speed, as well as daily rainfall values, were collected from the NAS PAGASA-UPLB-PCAARRD. In the absence of data from the NAS, daily solar radiations were empirically derived using CROPWAT 8.0. Daily ET_O were computed using the FAO-Penman-Monteith equation (FAOPM) in CROPWAT 8.0.

Plant heights were measured at each growth stage from five random plants from the plot. Leaf Area Index (*LAI*) is generally defined as the one-sided green leaf area per unit of ground surface area. *LAI* was determined by capturing a bird's eye view image using a digital camera and was computed as the ratio of leaf area to the area of land occupied by the plants in the given frame captured in the image. *LAI* plays a key role in the absorption of radiation, the deposition of photosynthates during diurnal and seasonal cycles, and in the pathways and rates of biogeochemical cycling within the canopy-soil system (Bonan, 1995; Van Cleve *et al.*,1983). *LAI* is a major component in understanding the ET_C per growth stage of rice.

Figure 3. Measurement of change on water depth in tank using micrometer hook gage.

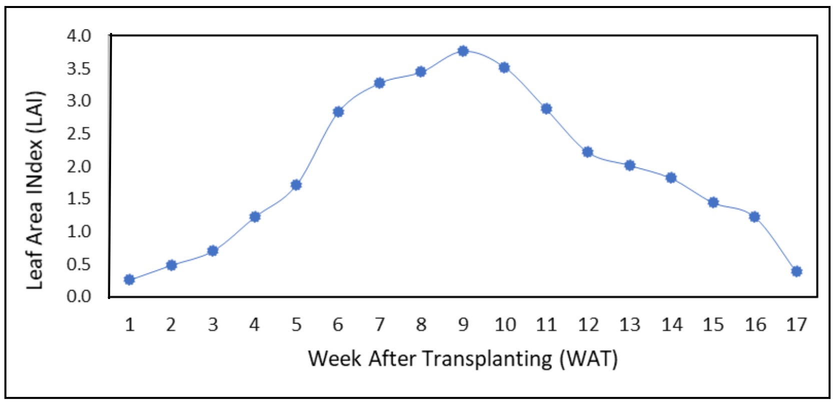

Figure 4. Changes of Leaf Area Index (*LAI*).

RESULTS AND DISCUSSION

Crop Evapotranspiration (ET_C)

The actual crop evapotranspiration (ET_C) was measured using the evapotranspiration tank. The results from the seepage and percolation tanks were not integrated anymore since they do not affect the measured ET_C which is the main focus of this report. The ET_C changes with every stage of crop growth due to the development of crop canopy and the difference in energy absorption. The interaction of rice canopy with the atmosphere, especially concerning radiation, is best described by *LAI* (Monteith and Unsworth, 1990).

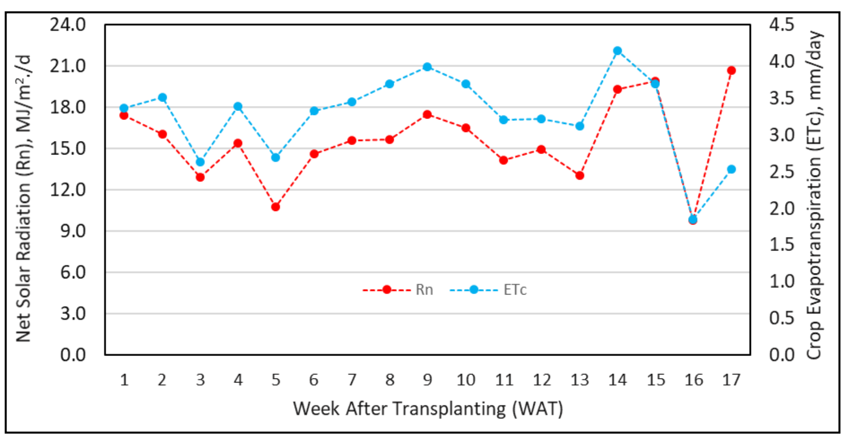

Figure 5. Weekly average of Net Solar Radiation () and Crop Evapotranspiration (ETc).

The measured *LAI* data is shown in Figure 4. A value of 1.0 was surpassed 4-weeks after transplanting (WAT) which means the leaf area was greater than the planted ground area. It continued to increase until it reached a maximum of 3.77 at 9 WAT and thereafter decreased due to leaf senescence. Changes in *LAI* and fluctuations in daily net solar radiation (R_n) significantly affect ET_C (Figures 5). Varying value of ET_C at 1 to 6 WAT and 12 to 17 WAT may be due to oscillation in R_n. Evapotranspiration during the initial stage was predominately in the form of evaporation (Allen et. al,1998). The highest ET_C of 4.15 mm/d was recorded 14 WAT when the net solar radiation was at its peak of 19.34 MJ/m^2/d while the *LAI* was merely 1.82. The increase in ET_C during this week may have resulted from increased evaporation because of high radiation and fewer leaves shading the standing water. The ET_C during unshaded and sunny conditions was primarily related to solar radiation (Fynn *et al*., 1993). The ET_C then slowly increased from 2.69 to 3.93 mm/d as *LAI* exceeded 2.5 even with minimal changes in net solar radiation, primarily because most of the radiation was intercepted by crop canopy and this increase was attributed mostly to crop consumption.

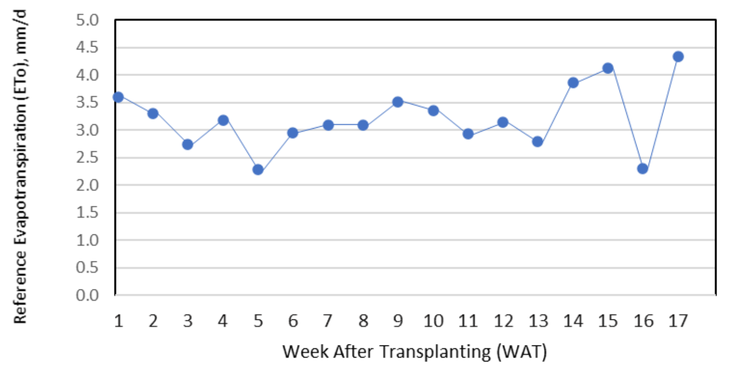

Figure 6. Weekly average of Reference evapotranspiration (ET_O).

The study adopted the IRRI average phenological stages for a 120-day variety: vegetative stage at 35 -55 days, reproductive at 35 days, ripening/late phase at 30 days (IRRI, n.d.). These were then adjusted based on field observations. The seasonal ET_C for the whole cropping season was 379 mm, and the daily average was 3.27 mm/d. Average ET_C per crop growth stage was 3.17 mm/d during the initial phase (0-21 DAT), 3.31 mm/d at vegetative stage (21-56 DAT), 3.55 mm/d during reproductive stage (56-98 DAT), and 2.70 mm/d at the late phase (98-120 DAT). The total water consumption due to crop evapotranspiration for the whole cropping season was computed to be 388.29 mm. This is less than the FAO approximate values ranging from 450-700 mm/cropping season (Brouwer & Heibloem, 1986). Considering that the total consumption was computed after transplanting which was 15 days after seeding, the actual value could be within the range. The peak ET_C values measured during the growing season were 3.69 mm/d, 4.15 mm/d, and 3/70 mm/d for the vegetative, reproductive and late phase, respectively. For comparison, peak ET_C values for the same growth stages were found to be 4.46 mm/d, 5.24 mm/d, and 5.46 mm/d in PAGASA, Muñoz and 3.75 mm/d, 5.26 mm/d, and 5.44 mm/d in PhilRice, Maligaya, both in Nueva Ecija, Philippines (Hafeez *et al*., 2002).

Reference Evapotranspiration (ET_O)

The computed ET_O using the FAOPM equation is shown in Figure 6. A comparison of Figures 5 and 6 showed that ET_O fluctuated corresponding to the changes in net solar radiation. Considering that the crop was planted in the dry season, the turbulent transport parameters such as humidity and wind speed may have fewer effects on ET_O during this period. The highest value of ET_O of 4.33 mm/d was recorded during 17 WAT, while the lowest of 2.28 mm/d was recorded at 5 WAT.

Crop Coefficient (K_C)

The computed K_C per growth stage of rice are shown in Figure 7. During the initial growth stage (0-3 WAT), K_C increased from 0.95 to 0.99. Values at the initial stage could be due to evaporation of the free water surface since the rice was transplanted in flooded paddy fields. K_C values further increased to an average value of 1.15 during the vegetative or crop developmental stage (4-8 WAT). This could be attributed to the increase in energy absorption of developing plant and soil heat flux. Soil heat flux, aside from net solar radiation, contributed energy for ET_C and was slightly larger at an early stage when the canopy was small (Hem *et al*., 1991). During the reproductive stage (9-14 WAT), the average K_C decreased to 1.14, although this is a very slight deviation from the previous stage and can be grouped all together or be considered as constant. This may be due to the decrease in *LAI*, which lowers the energy consumption of crops. At the late phase (15-17 WAT) of plant growth, K_C further decreased to 0.78. At this stage, *LAI* also decreased from 1.45 to 0.40, and the depth of standing water fell from 5 to 0 m as terminal irrigation is applied.

Table 1. Average crop coefficient (K_C) per growth stage as compared to data from David (1983) and FAO.

CROP GROWTH STAGE	DAT	WAT	K_C		
			Average	David, (1983)	(FAO)
Initial	0-21	0-3	1.02	0.95	1.05
Vegetative	21-56	4-8	1.15	1.05	1.20
Reproductive	56-98	9-14	1.14	1.10	1.20
Late	98-120	15-17	0.78	0.61	0.90 - 0.60

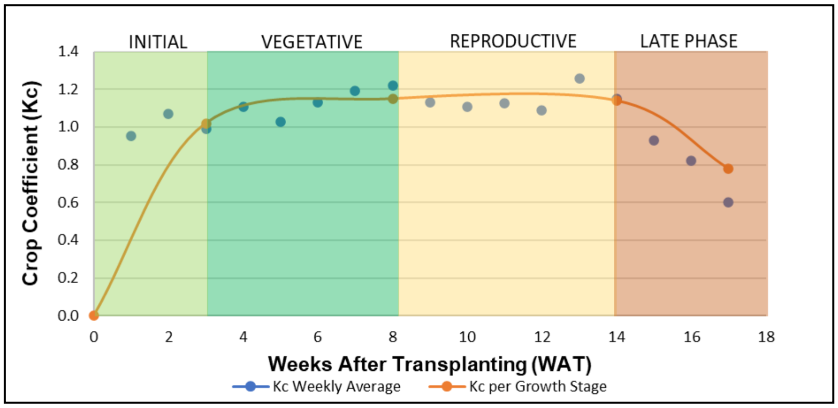

Figure 7. Changes in crop coefficient per growth stage.

Table 1 compares the generated K_C values with values obtained from lysimeter studies compiled by David (1983), as well as with FAO recommended K_C values. The K_C values in this study were higher than the values in David (1983) with a percent difference of 7.11%, 9.09%, 3.57% and 24.5% during the initial, vegetative, reproductive and late stages, respectively. The highest percent difference between the two studies was during the late stage when terminal irrigation and harvest is near. It should be noted that K_C values from David (1983) were based on potential evapotranspiration (ET_p or *PET*) obtained using the original Penman method for open water surface unlike the reference crop evapotranspiration used in this study. The ET_p was found to overestimate evapotranspiration computation, hence it was replaced with the current ET_O . On the other hand, the generated K_C values were slightly lower than FAO-recommended K_C values with a percent difference of only 2.9%, 4.26%, and 5.13% for the initial, vegetative, and reproductive stage, respectively. For the late stage, the generated K_C value is within the given range of between 0.9 and 0.6 in the FAO recommendation. While the K_C values were computed for the dry season only, they are generally close to both local values and FAO recommended values.

SUMMARY AND CONCLUSION

Knowledge of crop evapotranspiration (ET_C) throughout its growing period is very important in the determination of irrigation water requirements and helps in the proper design and management of irrigation systems. However, locally determined K_C information is very limited or is not available for many important crops in the Philippines, hence this research study. A modified microlysimeter was used to determine the ET_C of PSB Rc18 rice variety and the FAO Penman-Monteith equation was used to determine ET_O . The seasonal ET_C for the whole cropping season was 379 mm with a daily average of 3.27 mm/d. ET_C was significantly affected by plant development as reflected by its *LAI* and local microclimatic changes. The computed K_C values for rice during the initial, vegetative, reproductive, and late stages are 1.02, 1.15, 1.14, and 0.78, respectively. The difference in the K_C values for the vegetative and reproductive stage is very minimal and can be considered as constant. The estimated values of K_C are very close to the values given by FAO and David (1983) and can be used in the computation of crop water requirement and irrigation demands for rice in the Philippines. Nevertheless, it is recommended that a wet season cropping experiment be conducted to verify the applicability of the K_C values throughout the year.

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