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Crop Coefficient and Water Productivity in Conventional and System of Rice Intensification (SRI) Irrigation Regimes of Terrace Rice Fields in Indonesia

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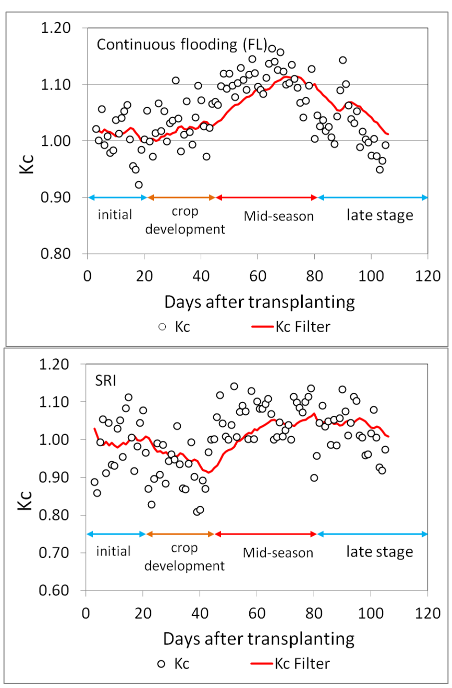
Graphical abstract



Abstract

The current study initiated to investigate crop coefficient (Kc) and water productivity between conventional and System of Rice Intensification (SRI) irrigation regimes of terrace rice fields in Indonesia. Kc value represents plant responses to available water in the fields and its information is very important to determine crop evapotranspiration. The field experiments were conducted in the terrace rice fields belong to the local farmer located in Wonogiri, Central Java (S 7°47'18.66", E 111°5'51.26") during 21 July – 7 November 2014 in the dry season. Here, there were two irrigation regimes with three replications, i.e. conventional flooding (FL) regime and SRI with intermittent irrigation (II) regime. Water level in each regime was measured by pressure sensor, while weather parameters such as solar radiation, air temperature, precipitation, etc were measured by particular sensors and connected to the developed field monitoring system. Based on weather and water level data, we estimated the average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, the average Kc values under SRI regime were a little bit lower than that FL regime. Their values were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. The reason was probably due to minimum soil evaporation under the drier soil condition. However, lower Kc values were not corresponded to the production of grain yield. Although it was not significant difference, we recorded that SRI regime produced 8.05 ton/ha grain yield, while FL regime was 7.63 ton/ha. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime.

Keywords: Crop coefficient, rice terrace, system of rice intensification, water management, water productivity

1.0 INTRODUCTION

Since introduced in 1999, System of Rice Intensification (SRI) has been widespread in some areas in Indonesia. However, paddy fields in Indonesia have various topographies such as terrace fields, so it is not easy to apply the SRI elements particularly in the water management. So, although many farmers have been trying to achieve high yield by SRI, yet accomplishment is not as desired.

In the SRI, paddy fields are not continuously flooded as common irrigation regimes in Indonesia, but conditioned dry during particular time, a practice called intermittent irrigation [1]. Many studies were carried in the different countries evaluating between SRI irrigation regime and conventional practice. SRI regime saved irrigation water significantly as reported previous studies. For example, SRI regime saved 26% water input in Indonesia [2], 28% in Japan, 38.5% in Iraq [3]. However, all experiments were conducted in the flood plain fields.

The current study initiated to investigate crop coefficient (Kc) and water productivity between conventional and System of Rice Intensification (SRI) irrigation regimes of terrace rice fields in Indonesia. Kc is commonly use for studying plant responses to available water in the fields whether in the dry or wet conditions. In addition, it is needed for irrigation scheduling and water resource allocation, management and planning [5]. Meanwhile, water productivity is important parameter to obtain the value or benefit derived from the use of water input [6].

The objectives of this study, therefore, were 1) determining crop coefficient of two different irrigation regimes, i.e., SRI irrigation regime and continuous flooding regime as representation of conventional rice cultivation practice in the terrace paddy fields, 2) comparing water productivity of those two irrigation regimes.

2.0 EXPERIMENTAL

2.1 Field Experiment

The experiment was conducted in Gemawang village, Giriwarto, District of Wonogiri, Middle-Java Indonesia with GPS position of S 7°47'18.66", E 111°5'51.26" during 21 July – 7 November 2014 in the dry season.

Here, we prepared two different water irrigation regimes with three replication, i.e., SRI regime (SRI) and Continuous Flooding (FL) for conventional rice cultivation practice. During initial and crop development (vegetative) stage (Figure 1), water level was kept at 1-2 cm above soil surface for FL regime and it was kept at very shallow water level near soil surface for SRI regime. Then, during reproductive (mid-season) stage, water level was kept at approximately 1 cm above soil surface for FL regime, while aerobic soil condition was developed for SRI regime. All plots were planted with a local rice variety (*Oryza sativa* L.), Ciherang, a current rice variety suitable for cultivation in Indonesia.

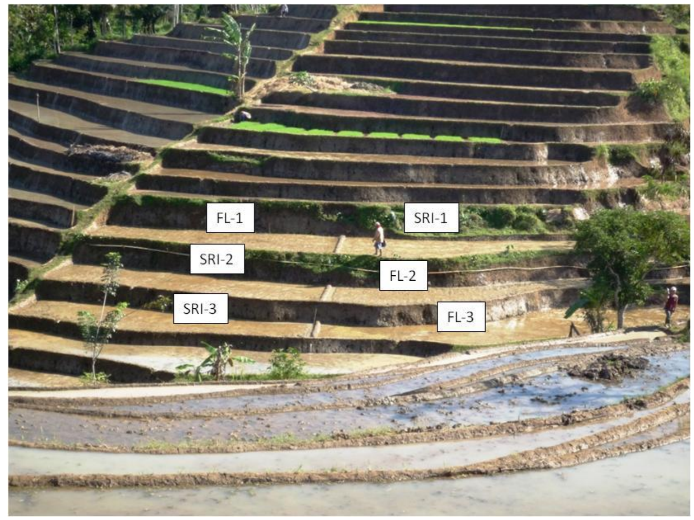


Figure 1 Experimental Paddy Fields in this study

2.2 Field Measurement

We used some sensors and data loggers to measure environmental biophysics parameters consisted meteorological and soil parameters. For meteorological parameters, we used *ECRN-100* rain gauge, *PYR* pyranometer, *EHT RH/Temp* sensors to measure precipitation, solar radiation and air temperature and relative humidity, respectively. Meanwhile for soil parameters, *5-TE* and *Hobo water level* sensors were used to measured soil moisture and water level in each plot. All sensors except Hobo water level sensor were connected *Em50 data logger* and the data were sent daily by *FieldRouter*.

2.3 Data Analysis

All environmental biophysics parameters were measured every 30 minutes, however, for data analysis we used daily data during planting period. Solar radiation and air temperature data were used to determine reference evapotranspiration (ETo) according to Hargreaves model [7, 8] as follow:

$$ET_o = 0.0135(T_{mean} + 17.78)Rs\left(\frac{238.8}{595.5 - 0.55T_{mean}}\right) \quad (1)$$

Where, ET_o is reference evapotranspiration (mm/d), T_{mean} is average air temperature (°C) and Rs is solar radiation (MJ/m^2/d).

Then, water balance analyses were performed to estimated crop evapotranspiration (ETc) using Excel Solver [9] according the following equation:

$$S_m(t) = S_m(t-1) + \Delta S(t) \quad (2)$$

$$\Delta S(t) = P(t) + I(t) + Gw(t) - Qr(t) - DP(t) - ETc(t) \quad (3)$$

Where, Sm is estimated water storage equivalent water depth(mm), ΔS is the change of water storage equivalent water depth (mm), P is precipitation (mm), I is irrigation water (mm), Gw is groundwater (mm), Qr is runoff/drainage (mm), DP is deep percolation (mm), ETc is estimated crop evapotranspiration (mm) and t is the time (day). Groundwater was assumed to be zero because its rate was negligible.

Sm was determined using water level data by the following equation:

Flooded:

$$S_m(t) = Z_r * \theta + WL(t) \quad \text{for WL(t)} > 0 \quad (4)$$

Non-flooded:

$$S_m(t) = Z_r * \theta \quad \text{for WL(t)} < 0 \quad (5)$$

Where, WL is water level (mm), Zr is effective soil depth layer (mm), and θ is volumetric water content (m^3/m^3). Here, we assume that effective soil depth layer is equal with root zone depth (approximately 300 mm)

Then, ETc was then used to determine crop coefficient by the following equation:

$$Kc = \frac{ETc}{ETo} \quad (6)$$

Where Kc is crop coefficient (unit less). Showing the trend in each growth stage, Kc value was filtered using Kalman Filter equation [10, 11]. Kalman filter is useful to show the trend when the daily change of crop coefficient is fluctuated with irregular trend. Average Kc value was then calculated based on FAO growth stage, that is divided into 4 stages namely, initial, crop development, mid-season and late stages.

Meanwhile, water productivity with respect of total water input [12] in each regime was calculated by the following equation:

$$WP = \frac{Y}{\sum (I + P)} \quad (7)$$

where Y is grain yield (ton/ha), WP is water productivity (g grain/kg water).

3.0 RESULTS AND DISCUSSION

3.1 Weather Condition During Planting Period

Figure 2 shows daily changes in air temperature and relative humidity during planting period. The trend of daily maximum air temperature was significantly increased (R^2 = 0.7) in which it value was approximately 30°C in the early period and 35°C in the late period. However, the trend was not followed by the trends of average and minimum air temperature as well as relative humidity. These trends were slightly stable in 20°C, 25°C and 80% for minimum air temperature, average air temperature and relative humidity, respectively.

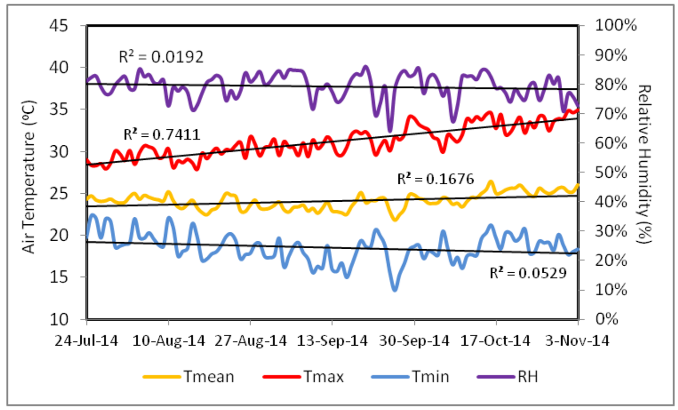


Figure 2 Daily changes in air temperature and relative humidity

The increasing maximum air temperature was supposed affected by increasing solar radiation as shown in Figure 3. Daily solar radiation was also significantly raised (R^2 = 0.35) from 15 MJ/m²/day on 24 July 2014 to be 25 MJ/m²/day on 3 November 2014. It was indicated that dry season was occurred during July – November 2014. Consequently, evapotranspiration was also increased significantly (R^2 = 0.43) from 3.5 mm/day in the early planting period to 6 mm/day in the late period. Therefore, the increasing evapotranspiration will also raised plant water requirement and irrigation.

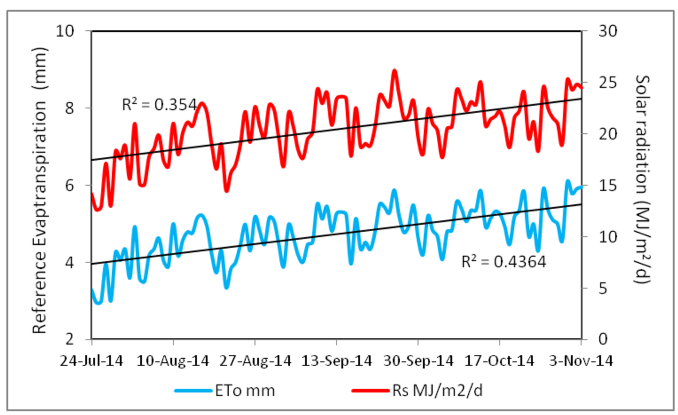


Figure 3 Reference evapotranspiration and solar radiation during planting period

3.2 Actual Water Level in the Fields

Crop coefficient is affected by the local climate as well as the change of water storage at the field [14].

Water storage in the field is commonly represented water level. Higher water level above soil surface indicates flooded condition and soil under saturated level. On the other hand, lower water level (probably below soil surface) shows less water storage and drier condition. Thus, it is important to consider the actual water level in studying crop coefficient between each regime (Figure 4).

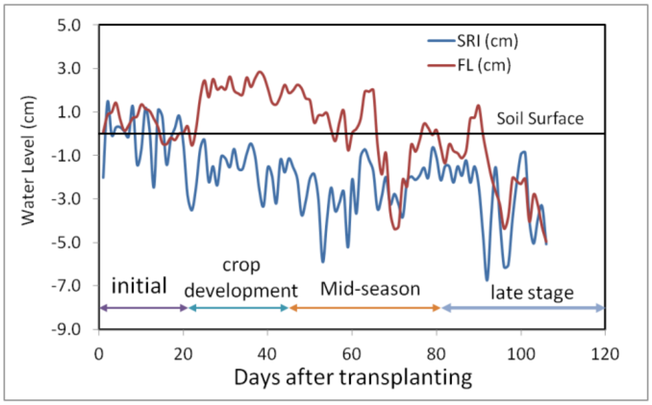


Figure 4 Actual water level between SRI and FL regimes during planting period

The actual water levels for both regimes were little bit different with the expected water level. In the crop development stage, it was expected the water level at very shallow water level near soil surface for SRI regime, however, the actual water level was at 1-3 cm below soil surface indicated that the field was drier than expected one. The same situation also occurred in the flooded regime in which water level was expected at 1 cm above soil surface in the mid-season stage, but it was dropped at 4.5 cm below soil surface. The occurrence was indicated that it was not easy to control water level in the terrace rice field manually without automatic water control system.

3.3 Crop Coefficient and Water Productivity

The daily crop coefficient (Kc) fluctuated widely throughout most of the planting period as presented in Figures 5 and 6. The Kalman filter method smoothed the data and provided continuous lines during the planting period for both regimes.

In the FL regime, when water level was at 1-3 cm above soil surface in the initial and crop development stages, Kc value was at the interval of 0.9 – 1.05. Then, it was rapidly increased in mid-season stage with maximum value of 1.18. Finally, it was declined rapidly in the late season stage with minimum value of 0.93. Its value declined when the plant focused on grain development in which the field became drier starting in the end of mid-season stage as shown in Figure 4.

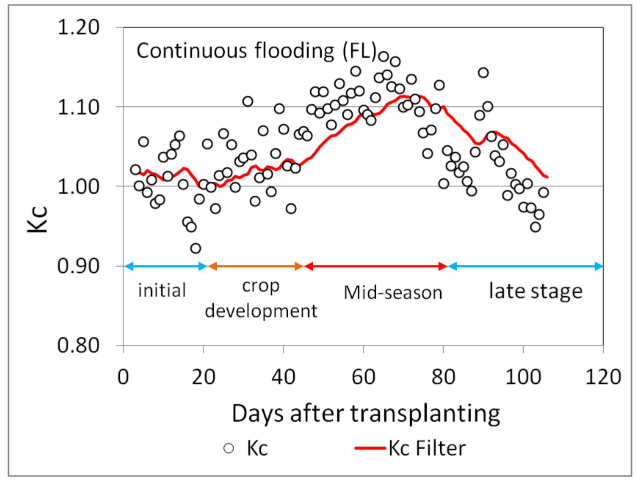


Figure 5 Daily crop coefficient curve of FL regime

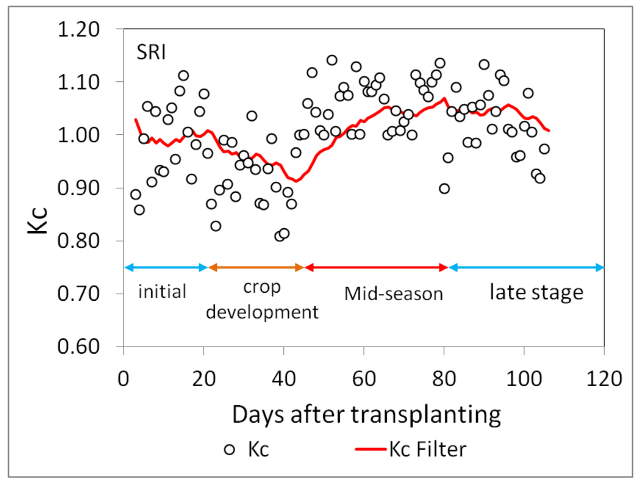


Figure 6 Daily crop coefficient curve of SRI regime

Meanwhile, in the SRI regime, Kc value was slightly decreased in the initial and second stages as responses of the decreasing of water level during this period with minimum Kc value was 0.8. The water level was dropped from 1 cm above soil surface to be 5 cm below soil surface in the end of crop development stage (Figure 6). Then, it was gradually increased in the mid-season stage when the plant initiated generative phase in development of tillers and panicles. Finally, it was declined gradually with minimum Kc value was 0.90 in the late stage. Commonly, in the late stage when water was drained and the plant exhibited full senescence, Kc value declined as responses of water availability in the fields [9].

Table 1 Crop coefficient and water productivity in each irrigation regime

Parameter	Irrigation regimes		FAO's Kc Value
	FL	SRI	
Average crop Coefficient in each growth stage:			
Initial Stage	1.01	1.00	1.10 - 1.15
Development Stage	1.02	0.96	1.10 - 1.15
Mid-season Stage	1.09	1.02	1.10 - 1.30
Late Stage	1.05	1.04	0.95 - 1.05
Water input:			
Precipitation (mm)	0	0	
Irrigation water (mm)	536	518	
Crop evapotranspiration (mm)	517	496	
Grain Yield (ton/ha)	7.63	8.05	
Water Productivity (g grain/kg water)	1.42	1.55	

Table 1 record the comparison of the average Kc values for both regimes compared and the typical ranges reported by the FAO for rice cultivation under the standard conditions [13]. In the initial stage, both average Kc values for the SRI and FL regimes were lower than the FAO value since the actual field conditions were drier than the FAO standard conditions. The minimum Kc value of SRI regime indicated minimum levels of both evaporation and transpiration rate.

The same could occur in the crop development stage when average Kc value for the SRI regime was also lower than that for the FL regime. Water stress (drying period) has affected on lower Kc value over several days (Figure. 4). In this growth stage, Kc value varies depending on crop type and frequency of soil wetting [14]. Therefore, drier field also should have corresponded to the decreased Kc value in this stage. Commonly, in the initial and crop development stages water used is directly proportional to transpiration, as a result when the field became drier, the most effective response of the plant is to reduce the transpiration [15].

In the mid-season and late stages, SRI regime has also lower Kc values than that FL regime when the water availability in the field less than FL regime represented by lower water level (Figure 4). Particularly in the late stage, Kc values for both regimes were comparable and their values were within FAO's Kc value. With lower Kc values in most growth stages, therefore, total crop evapotranspiration of SRI regime was lower than that FL regime.

Interestingly, although has lower Kc values during planting period, however, SRI regime produced more grain yield than that FL regime (Table 1). It was indicated that SRI regime more effective in the development of number of tillers and panicles. The key of SRI regime was aerobic condition particularly in mid-season stage in which this condition was effective to avoid spikelet sterility particularly around the flowering time [12]. In addition, SRI regime provided provides optimal water and oxygen availability with alternate wetting and drying irrigation system [16].

SRI regime with drier condition than that FL regime need less irrigation water (Table 1). Accordingly, with more grain yield and less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively. It was indicated that SRI regime more efficient in water use than that FL regime. Thus, SRI regime has more benefit or value derived from use of water.

4.0 CONCLUSION

Crop coefficient (Kc) of SRI and continuous flooding (FL) regimes in terrace paddy fields were well determined by water balance analysis with Excel Solver estimation. SRI regime has lower Kc values than that FL regime in all growth stages. Average Kc values for SRI regime were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Although has lower Kc values, however, SRI regime produced more grain yield than that FL regime. The main reason was probably due to aerobic condition under SRI regime which provided optimal water and oxygen availability. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively.

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