EVALUATION OF CROP COEFFICIENTS FROM WATER CONSUMPTION IN PADDY FIELDS

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ABSTRACT

Crop coefficient was evaluated from water consumption of various treated paddy fields on the objective to find its changes with time as the plant grew. Three principal techniques of paddy fields known as the commonly practiced, Integrated Crop Management (ICM) and System of Rice Intensification (SRI) were investigated. Its of them has 2 major different irrigating and planting patterns, which has different performance on plant growth as well as productivity. In this study, the combinations of irrigating and planting patterns across these 3 systems also investigated, and in total there were 36 treatments. Measurements were conducted in daily basis on water level, soil water, draining water, ponding water, irrigation water, and weather parameters such as temperature, wind velocity and sunshine duration to calculate potential evapotranspiration by means of FAO Penman Monteith model. Water balance analysis was carried out to calculate equivalent depth of soil water, which was then compared with measured soil water based on water level data and soil water retention curve. Optimization process was then conducted to find daily crop coefficients with the objective to minimize a cumulative different between calculated and measured soil water depths. The results show that each treatment produced different temporal crop coefficients but more or less had similar patterns in the early, middle and late stages of the plant growth. In consequence, temporal crop coefficient is important to take into account for irrigation planning on different systems of paddy field especially to earn optimum water efficiency.

Keywords: paddy field, crop coefficient, water efficiency

INTRODUCTION

Nowadays, many paddy intensification method has been developed to enhance productivity. Two methods that has been applied widely by farmers in Indonesia was System of Rice Intensification (SRI) and Integrated Crop Management (ICM).

SRI was originally developed in Madagascar. SRI emphasizes the integrated management of soil, crop, water and nutrients. The application of SRI in Indonesia was initially developed in West Java with various modifications adapted to the local conditions and potential (Kasnawi, 2005). Some characteristic of SRI growing in

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West Java was intermittent irrigation (irrigation timing is determined based on the visual condition of the soil), shallow planting with “L” shaped root, one seed per-hill, wide spacing (20x20 cm, 25x25 cm, or more) , weeding four times or more, integrated pest management and recommended to apply organic fertilizer without chemical fertilizer. In addition to compost, farmers also developed organic fertilizer using materials that were easily available in the field, such as fruit waste, vegetables waste, etc. The materials are fermented and applied in liquid form. Farmers often calls this fertilizer as local microorganism or in the abbreviation MOL (*Mikro Organisme Lokal*).

ICM was developed by Indonesian Center for Rice Research. This method combines the principles SRI, integrated pest management and some adjustments to local conditions (Agricultural Research and Development Agency, 2008). Some characteristics of ICM was the use of superior or high-yielding rice varieties, use certified high quality seeds, use a balanced fertilizer depend on location conditions, use compost and organic matter or manure as a fertilizer, use of legowo, tiles or direct seeding planting system while maintaining a minimum population, planting seedlings with a young age in limited number of seedlings per hill (ie between 1-3 seeds per hill), intermittent irrigation, weed control, pest control with integrated pest management concepts and use of mechanical or manual thresher.

Due to differences in planting and irrigating patterns, these methods resulting differences in performance of growth as well as productivity. However, whether these methods produce different crop coefficient is not well known. This research aims to evaluate crop coefficient from water consumption of various treated paddy fields on the objective to find its changes with time as the plant grew.

MATERIALS AND METHODS

Location

Field experiment was carried out at Cikarang Sari village, district of Cikarang, Bekasi. Paddy filed in this region have alluvial soil type, heavy clay soil texture, slow permeability rate (low percolation rate), shallow ground water depth, soil pH (H_2O): 5.8 and low-organic C content (1.7%). This region have 3-4 wet months and 5-6 dry months, the maximum temperature of 32.0 ^oC-33.8 ^oC (September) and daily average temperatures around 27.6 ^oC. This research was conducted at first cropping season in month December 2007 until March 2008 (wet season).

Plot Treatments

Three principal techniques of paddy fields known as the commonly practiced, Integrated Crop Management (ICM) and System of Rice Intensification (SRI) were investigated. Its of them has 2 major different irrigating and planting patterns, which has different performance on plant growth as well as productivity. In this study, the combinations of irrigating and planting patterns across these 3 systems also investigated. Rice variety used in this field experiment was Sintanur that have crop age 115-125 Days After Seeding (DAS).

Experimental plots were arranged using split plot experimental design in 3 repetition so in total there were 36 plots. The main plot were planting pattern denotes in symbol C, I and S representing commonly practiced, Integrated Crop Management (ICM) and System of Rice Intensification (SRI). Detailed description of each planting pattern treatment described as in Table 1

The sub plot were irrigation pattern denotes in symbol A1, A2, A3 and A4. A1 was irrigating pattern similar to irrigation method used by SRI farmer at east java. Irrigation conducted when hair crack open until shallow ponding or saturation. Hair crack opened when soil water table reached about -10 cm. A2 was modification of A1 pattern that used dryer limit to decide irrigation. Irrigation conducted when larger crack open until shallow ponding or saturation. Larger crack open when soil water table reached about -20 cm. A3 was irrigating pattern used by ICM farmer, including combination of ponding and drying in some crop growth stage. A4 was irrigating pattern used by local farmer by maintaining ponding depth at 0-5 cm. Detailed description of each treatment described as in Table 2.

Table 1. Planting pattern description

Parameters	Commonly Practiced (C)	Integrated Crop Management (I)	System of Rice Intensification (S)
Seeding	Wet seeding, age 30 days for transplanting	Dry seeding, age 10 days for transplanting	Dry seeding, age 10 days for transplanting
Transplanting	5-10 seedlings per hills at 20x20 spacing	1-2 seedlings per hills at 25x25 spacing	1 seedlings per hills at 25x25 spacing
Weeding	1-2 times during vegetative growth stage (tillering)	1-4 times during vegetative growth stage (tillering)	4 times during vegetative growth stage (tillering) at 10, 20, 30 and 40 DAT[3]
Fertilizer use	Chemical fertilizer based on guideline of agricultural officer	Compost at land preparation, then chemical fertilizer applied based on guideline of agricultural officer and leaf color chart	Organic fertilizer (compost and MOL/local indigenous liquid fertilizer)

Table 2. Irrigating pattern description

Parameters	A1	A2	A3	A4
Water management at initial stage (± 0-10 DAT)	Maintained at saturation. If rain occurred, drainage until 0 cm ponding.	Maintained at saturation. If rain occurred, drainage until 0 cm ponding.	Maintained at saturation for 3 days, then shallow ponding until tillering. If rain occurred, drainage until 0 cm ponding.	Ponding maintained at 2 to 5 cm. If rain occurred, drainage until 5 cm ponding.

[3] DAT : Days After Transplanting

Parameters	A1	A2	A3	A4
Water management at vegetative stage (± 11-50 DAT)	Intermittent irrigation (irrigated when small crack in soil visually observed until saturation). Shallow ponded (± 2 cm) for weeding at 10, 20, 30 and 40 DAT. If rain occurred, drainage until 0 cm ponding.	Intermittent irrigation (irrigated when larger crack in soil visually observed until saturation). Shallow ponded (± 2 cm) for weeding at 10, 20, 30 and 40 DAT. If rain occurred, drainage until 0 cm ponding.	Drying for 5 days then intermittent irrigation (irrigated when ponding water reach 0 cm until 2 cm) until 5 days before generative stage. Afterward, drying until generative stage. If rain occurred, drainage until 0 cm ponding.	Ponding maintained at 2 to 5 cm. If rain occurred, drainage until 5 cm ponding.
Water management at flowering and heading stage (± 51-85 DAT)	Intermittent irrigation, irrigated when small crack in soil visually observed until shallow ponding (± 2 cm). If rain occurred, drainage until 0 cm ponding.	Intermittent irrigation, irrigated when larger crack in soil visually observed until shallow ponding (± 2 cm). If rain occurred, drainage until 0 cm ponding.	Shallow ponding maintained at flowering then intermittent irrigation (irrigated when ponding water reach 0 cm until 2 cm) at heading. If rain occurred, drainage until 0 cm ponding.	Ponding maintained at 2 to 5 cm. If rain occurred, drainage until 5 cm ponding.
Water management at ripening stage (± 85-95 DAT)	Keep the soil dry without irrigation. If rain occurred, drainage until 0 cm ponding.	Keep the soil dry without irrigation. If rain occurred, drainage until 0 cm ponding.	Keep the soil dry without irrigation. If rain occurred, drainage until 0 cm ponding.	Keep the soil dry without irrigation. If rain occurred, drainage until 0 cm ponding.

Measurements

Measurements were conducted in daily basis on water level, soil water, draining water, ponding water and irrigation water. Weather parameters such as temperature, wind velocity and sunshine duration collected to calculate potential evapotranspiration by means of FAO Penman Monteith method.

Data Analysis

Water balance analysis conducted on daily basis (Figure 1) as expressed in Equation 1.

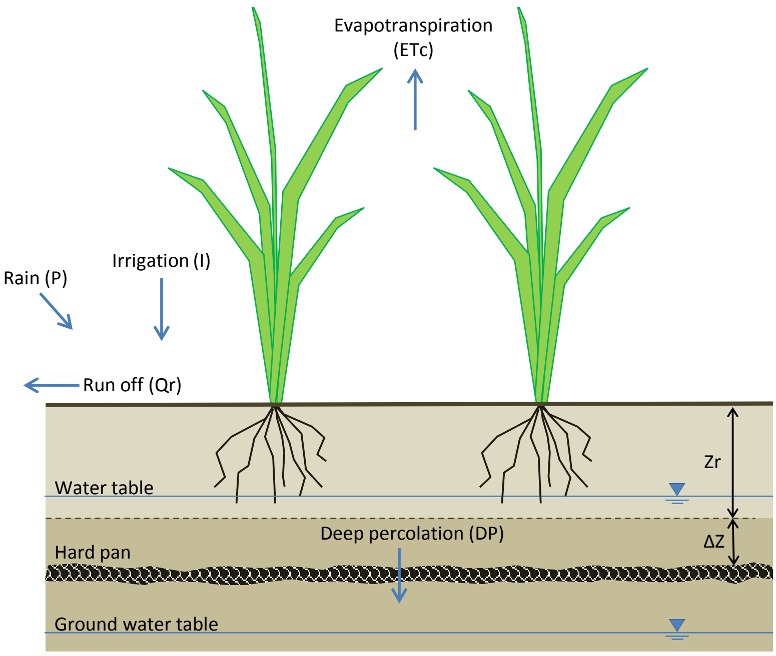

Figure 1. Water balance schema in paddy field

$$\frac{dS}{dt} = P + I + Gw - Qr - DP - ETc \quad (1)$$

where $\frac{dS}{dt}$ is the change in soil water storage equivalent with water depth (mm), WL is water level measured from soil surface (mm), P is precipitation (mm), I is irrigation water (mm), Gw is groundwater (mm), Qr is run off/drainage water (mm), DP is deep percolation (mm) and ETc is crop evapotranspiration (mm). The soil depth was assumed consist two layers where the first is effective depth (root zoning/Zr) and the second one is root zone to hardpan layer (ΔZ). The effective depth (Zr) was determined by the minimum water level that can be reached during cultivation time in each treatment. If Gw was assumed zero and $Net = R + I - Qr - P$ then Equation 1 can be expressed as:

$$\frac{dS}{dt} = Net - ETc \quad (2)$$

ETc is crop evapotranspiration calculated as follows:

$$ETc = Kc \times ETo \quad (3)$$

Where Kc is crop coefficient and ETo (mm) is potential evapotranspiration calculated using FAO Penman Monteith method as in Equation 4 (Allen et.al, 1998).

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (4)$$

Where ET_o is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s - e_a is saturation vapour pressure deficit (kPa), D is slope vapour pressure curve (kPa $°C^{-1}$) and g is psychrometric constant (kPa $°C^{-1}$). Thus, Equation 2 can be futher expressed as follows:

$$\frac{dS}{dt} = Net - Kc \times ETo \quad \text{.......} \quad (5)$$

$\frac{dS}{dt}$ was compared with measured soil water based on water level data and soil water retention curve (Equation 2) to find cumulative error used in optimization process.

$$\theta\ \psi\ = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + \ \alpha|\psi|^n\ \right]^m} \quad \text{.......} \quad (3)$$

where θ(φ) is water retention curve, |ψ| is suction pressure (cm of water), θ_s is saturated water content, θ_r is residual water content, α is coefficients related to the inverse of the air entry suction (cm^{-1}), n and m is measure of the pore-size distribution. α, n and m were optimized using data observed from the field. Optimization resulting water retention curve as in Figure 2. Soil water calculated for two assumed soil layer Zr and ΔZ.

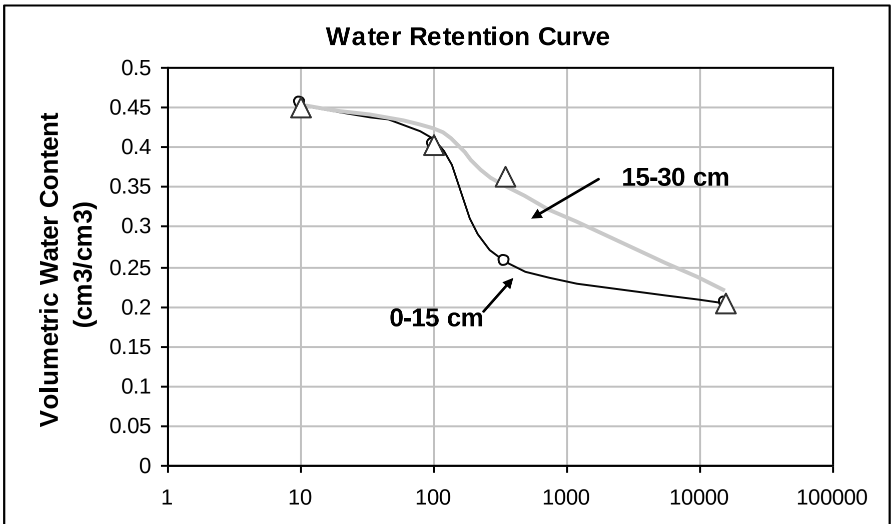

Figure 2. Daily crop coefficient for each planting pattern treatment

Optimization process then conducted using Microsoft Excell Solver to find Kc and Net with the objective to minimize a cumulative differences between calculated and measured soil water depths. Furthermore, Kc value in each growth stage was filtered by using Kalman Filter Equation (Kalman, 1960; Welch and Bishop, 2006) to show the trend and estimate the state of process.

RESULT AND DISCUSSIONS

Daily crop coefficients was optimized in each plot and resulting daily crop coeffient as in Figure 3.

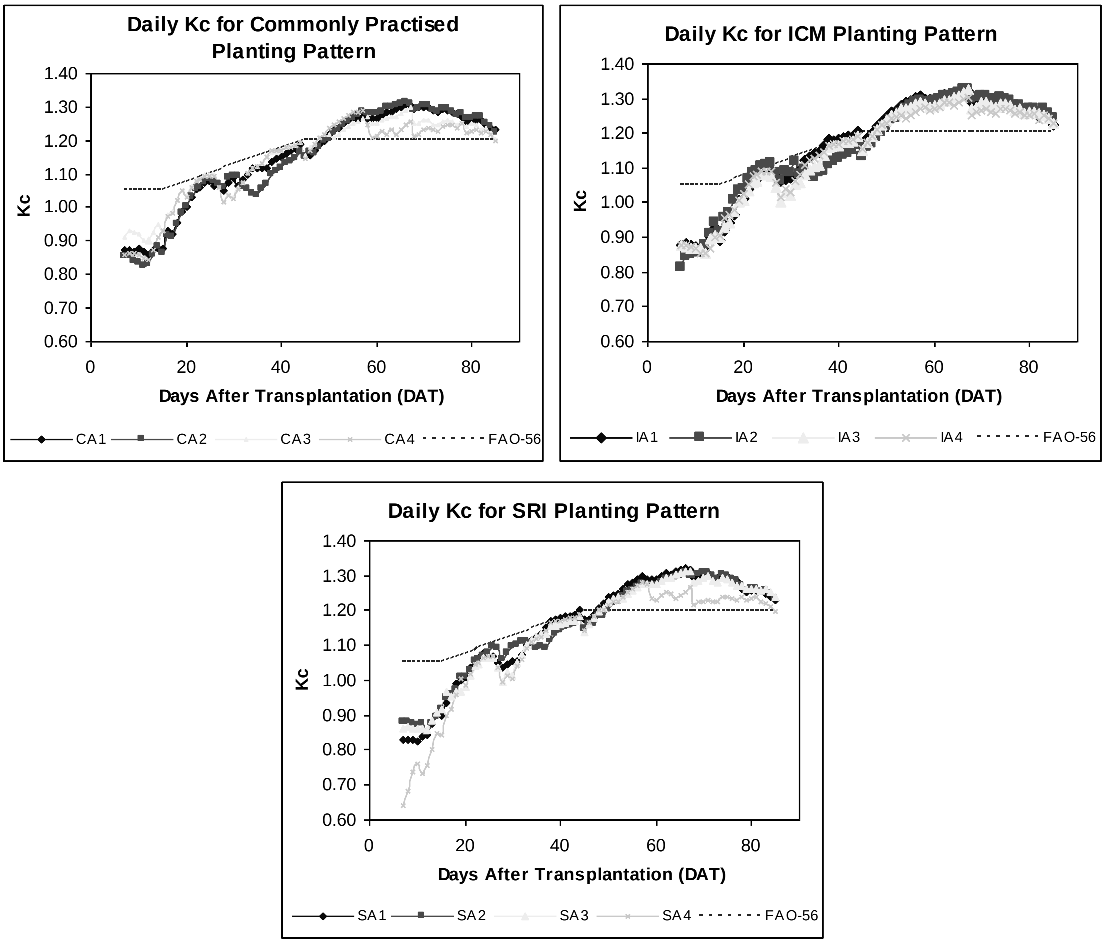

Figure 3. Daily crop coefficient for each planting pattern treatment

Each treatment has different temporal crop coefficients but more or less had similar patterns in the early, middle and late stages of the plant growth. This pattern was also similar to temporal crop coefficient pattern in Allen et.al (1998). Crop coefficient was relatively small at 0-15 DAT then rapidly increasing in development stage at about 16-45 DAT. Afterwards, crop coefficient start reaching maximum value at about 46-75 DAT and then decreased at 76-85 DAT. After 85 DAT, each plot left to dry without irrigation to enhance grain ripening. Although, the result were lower at initial and development stage but higher at mid stage. This variation may caused by different condition used to estimate crop coefficient. As explained by Faharani et.al (2007), the effect of local climate, soil, management and irrigation may caused variation of crop coefficient. Crop coefficient from Allen et.al (1998) are most suitable in sub-humid climates with average daily minimum relative humidity values of about 45% and calm to moderate wind speed averaging 2 m/s.

Planting and irrigating treatment effect on crop coefficient can be further explained using statistical analysis. To ease the analysis, daily crop coefficient averaged into 15 days period then analysis conducted using two way ANOVA at level of 5%. Interaction p-value result for 1-15, 16-30, 31-45, 46-60, 61-75 and 76-85 DAT respectively 0.9994, 0.9996, 0.9681, 0.9748, 0.6109 and 0.6588. Each 15 days period averaged crop coeficcient has interaction p-value > 0.05 indicating that planting pattern and irrigating pattern treatment insignificantly influenced crop coefficients. Therefore, this result showed that different planting and irrigating pattern produce similar crop coefficient.

When observed from the temporal variation, crop coefficient has significant differences according to growth phase. Statistical analysis was performed using one-way ANOVA at 5% level and then continued with the Tukeys test. Results of analysis as in the **Table 3**. Crop coefficients tend to increase at 1-45 DAT then stabilized at maximum value at 46-85 DAT.

Table 3. Temporal crop coefficient analyses

DAT	Mean*	StDev
1-15	0.87a	0.2341
16-30	1.03b	0.1036
31-45	1.13c	0.0358
46-60	1.24d	0.0279
61-75	1.28d	0.0316
76-85	1.25d	0.0196

* means followed by common letter are not significanty different at 5% level

These crop coefficients was slightly different with crop coefficient recommended by Irrigation Design Criteria (Directorate of Irrigation, 2009) as in **Table 4**.

Table 4. Comparison between kc from Irrigation Design Criteria and research result

Crop age (month after transplanting)	Local varieties	High yield varieties	Research result
0,5	1,20	1,20	0.87
1	1,20	1,27	1.03
1,5	1,32	1,33	1.13
2	1,40	1,30	1.24
2,5	1,35	1,30	1.28
3	1,24	0	1.25
3,5	1,12		
4	0		

Crop coefficient recommended by Irrigation Design Criteria was overestimated crop coefficients in this research result. To increase irrigation efficiency, crop coefficient used in irrigation operation planning should be adjusted to lower value especially in vegetative stage at 0.5-1.5 month after transplanting.

SUMMARY AND CONCLUCIONS

Optimization method developed in this paper resulting satisfying temporal crop coefficient value. Each treatment produced different temporal crop coefficients but more or less had similar patterns in the early, middle and late stages of the plant growth. Statistical analyses showed that different planting and irrigating pattern produce similar crop coefficient. Although, this value were slightly different compared to crop coefficient in Indonesian Irrigation Design Criteria especially in vegetative stage at 0.5-1.5 month after transplanting. In consequence, temporal crop coefficient is important to take into account for irrigation planning on different systems of paddy field especially to earn optimum water efficiency.

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