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Research Article

Enhanced Water Use Efficiency by Intermittent Irrigation for Irrigated Rice in Indonesia

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ABSTRACT

Keywords
Water management, water use efficiency, paddy fields, intermittent irrigation.

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In Islamic perspective, water resource should be managed properly and used in a sustainable way including for irrigated rice in Indonesia. Continuous flooding irrigation that commonly used in rice production characterized by insufficient water use because the quantity of irrigation water is usually supplied to the field greater than plant water requirement. The current study was performed to evaluate intermittent irrigation in raising water use efficiency for rice production in Indonesia particularly in the rainy season. Achieving this goal, a field experiment was conducted in Karang Sari Village, Bekasi, West Java, Indonesia during the first rice season 2007/2008 (December 2007 to April 2008) in the rainy season. Here, two irrigation regimes were compared i.e., intermittent irrigation (II) regime and continuous flooding (CF) regime. As the results, it was clearly observed that II regime raised water use efficiency index up to 37.6% by saving water input up to 26.07% compared to CF regime. The II regime also reduced excess water through percolation and runoff significantly. The II regime also resulted in better yield and crop performance compared to continuous flooding irrigation even if not significant. The main reason is that under intermittent irrigation, aerobic condition was created. This condition promoted higher activity of the plants for the establishment of a larger and deeper root as reported previous studies. Therefore, the results suggested that intermittent irrigation is suitable way to raise water use efficiency without decreasing yield for irrigated rice in Indonesia.

1. INTRODUCTION

Rice (*Oryza sativa* L) has become the most important staple food in Indonesia, and it covers the largest agricultural area. The total harvested area and rice production in 2011 were 13.2 million ha and 65.8 million tons, respectively (Statistics Indonesia 2011). Recently, the challenges related to improving rice productivity in Indonesia have been increasing due to the increased population and reduced arable area. In addition, climate change issues have been affecting paddy irrigation water requirements during the rainy and dry seasons (De Silva et al. 2007). Hence, an alternative irrigation system that produces more rice with less water input is needed to ensure a sufficient food supply.

Commonly in Indonesia, rice is cultivated under continuous flooding irrigation by maintaining the depth of water between 2 and 5 cm to control weeds, reduce the frequency of irrigation, and secure against possible future shortage of water due to the unreliable water delivery system. Consequently, agriculture is the largest consumer of fresh water especially for irrigation. The data in 2010 showed that water used for irrigation was 89% following by fisheries (7%), domestic and industrial (4%) and livestock (0.2%) (Radhika et al. 2012). Continuous flooding irrigation is less efficient because the quantity of irrigation water is usually greater than actual water requirement. This weakens water saving effects, causing large amounts of surface runoff, seepage and percolation (Bouman 2001). Also, excessive water use without considering plant water requirement is contrary to the principles of Islam.

According to Islam, water should be used as its requirement and excessive in water use should be avoided (*The Holy Qur'an*, Al A'raf: 31). In addition, water resource is a finite, thus the mankind as leader (caliphate) in the earth should maintain it in the better way (*The Holy Qur'an*, Al Mu'minun: 18, Az Zuhruf: 11, Al Mulk: 30). This principle is also adopted in Dublin Statement

(Principle 1) that stated "fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment." (Dublin statement, 1992). Water is a social good and a gift from God, thus water resources must be managed and used in a sustainable way (Faruqi 2001).

Therefore, water resource should be managed properly including for irrigated rice in Indonesia based on plant water requirement. One strategy to promote water saving for better water resource management in rice production without significant yield losses is by adopting intermittent irrigation (Won et al. 2005). In this irrigation system, the field is kept saturated or under shallow standing water, and then keep the soil dry for particular periods instead of continuously flooding. Many researches have been conducted to verify this system. As the results, it was clearly observed that this system can increase water use efficiency significantly by saved water input as provided data for different countries, e.g., in Japan (Chapagain and Yamaji, 2010), 38.5% in Iraq (Hameed et al. 2011), 43.9% in China (Lin et al. 2011). The results revealed that the increasing water use efficiency by intermittent irrigation varied among different countries. This was due to different climate, rice variety and soil type among the countries.

However, there is lack information on raising water use efficiency of intermittent irrigations for irrigated rice in Indonesia compared to continuous flooding irrigation for the specific location and season. The aim of the current study is to investigate enhancing water use efficiency of intermittent irrigation compared to continuous flooding irrigation for rice cultivation in Indonesia particularly in the rainy season.

2. MATERIALS AND METHODS

2.1. Experimental Field

This study was conducted in the paddy fields in Karang Sari village, district of Cikarang Timur, Bekasi, West Java, Indonesia during the first rice season 2007/2008 (December 2007 to April 2008) in the rainy season. The soil was alluvial and had a heavy clay texture with a soil pH of 5.8 and low organic matter content (1.7%). Here, we prepared six plots and each plot was a 9.6 m x 18 m rectangular shape. All plots were planted with the local variety of rice (*Oryza sativa* L), *Sintanur*, a hybrid rice variety. We involved the following cultivation practices; single planting of young seedling (10 days after seedling) spaced at 30 x 30 cm, using an organic fertilizer at 7 tons/ha and no chemical fertilizer. Moreover, indigenous microorganisms grown in a bamboo sprout and fruits mixture were supplied to the field 10, 20, 30, 40 and 50 days after transplanting (DAT). The indigenous microorganisms enhance the biological activity of the soil (Uphoff and Kassam 2008). Plant growth was observed and recorded every ten days, starting from 15 DAT. For each plot, we measured plant height and number of tillers/hill to assess effects of different irrigation regimes on plant performances.

2.2. Water Management

The experimental design was a single factorial design with three replications. Data were analyzed by one-way analysis of variance (ANOVA) hypothesizing irrigation regime to be the significant source of variation. The detail irrigation regimes, named as Intermittent Irrigation (II) and Continuous Flooding (CF) as illustrated in Figure.1.

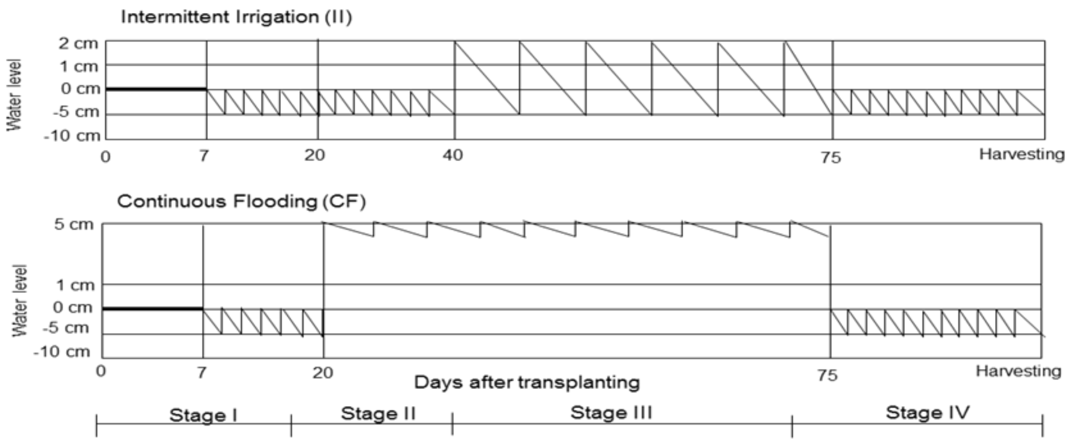

Figure 1. Irrigation regimes applied in the fields.

For the II regime, the soil was kept moist but with no standing water during vegetative stage, i.e., stage I (initial) and stage II (crop development stages), then shallow standing water ranging in depth from −5 to 2 cm was applied during reproductive stage (stage III) and finally water was drained to maintain saturated soil until harvesting day (stage IV). Meanwhile, for CF regime, the field was maintained by ponding water with the interval 2-5 cm water depth during planting period except stage I, then in the stage IV, water was drained to maintain saturated soil until harvesting day.

2.3. Water Use Efficiency

Water saving

Water saving as an advantage of the II regime was calculated using the following equation:

$$\text{Water saving for the period}(\%) = \frac{\sum I_{CF} - \sum I_{II}}{\sum I_{CF}} \text{x}100 \quad (1)$$

where, I_{CF} and I_{II} are irrigation water (mm) for CF and II regimes, respectively. Total irrigation water for each regime was estimated by water balance analysis.

Water use efficiency index (WEU)

As a measure of crop yield (dry matter) per unit water supplied, water use efficiency index (Van der Hoek et al. 2001) is defined as;

$$\text{WUE (kg/ha/mm)} = \frac{\text{Yield(kg/ha)}}{\sum \text{Irrigation water (mm)}} \quad (2)$$

Water productivity

Furthermore, we calculated water productivity (WP) to look up another water-rice production relationship (Molden et al. 2003). In paddy fields, WP is calculated using the following equation (Van der Hoek et al. 2001):

$$\text{WP (kg/ha/mm)} = \frac{\text{Yield(kg/ha)}}{\text{Total water consumption by crop evapotranspiration (mm)}} \quad (3)$$

where, total water consumption by crop evapotranspiration (mm) derived from water balance analysis

2.4. Water Balance Analysis

Water balance analysis was performed to determine the water supply and water use within the crop season in daily basis based on the following equation:

$$\frac{dS}{dt} + WL = P(t) + I(t) + Gw(t) - Qr(t) - DP(t) - ETc(t) \quad (4)$$

where $\frac{dS}{dt}$ is the change in 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 runoff (mm), DP is deep percolation (mm) and ETc is crop evapotranspiration (mm). Here, Gw, water that comes from the ground, was assumed to be zero due to the negligible rate.

Here, precipitation (P) was measured by a rain gauge and water level (WL) was measured by a piezometer. Meanwhile, runoff was defined as excess water from precipitation that was removed from the field artificially to maintain desired water levels during the planting period and its rate was measured by a water meter. Then, the change in water depth was calculated based on a soil retention curve by using Genuchten model (Van Genuchten 1980).

To calculate the other parameters such as percolation, Microsoft Excel's Solver was used as described by Abdel-Fattah et al. (2009) and the guide to use it could be referred to Morrison (2005). In this study, we tried to find the combination of the parameters to minimize the following error:

$$\text{Error for the period} = \sum \left| S_o - S_m \right| \quad (5)$$

where, S_o is daily-observed soil water storage (water depth mm), S_m is model based soil water storage (mm) estimated by the Excel Solver estimation.

3. RESULTS AND DISCUSSION

3.1. Water balance in the fields

Both irrigation regimes were carried out to maintain the water level at the interval level during the crop season, as described previously (Figure. 1). However, measurement of the actual water level was quite different from that of the desired water level, as affected by high precipitation in the rainy season (Figure 2). This occurred when the restarting of irrigation time was determined visually and the natural environment was unpredictable, particularly in terms of precipitation. Even if it was kept saturated for 7 to 20 days after transplanting (DAT), the actual water level dropped below the soil surface, particularly within 12 to 17 DAT due to the high evaporation that occurred on some days. Furthermore, the actual water level increased dramatically on 20 DAT and reached approximately 10 cm above the soil surface in both water management regimes. This was caused by a high amount of precipitation (136 mm) over three days.

Within the period of 20 to 40 DAT, water stresses were likely to exist for both water management regimes, as illustrated by the lowest water level in Figure. 2. At that time, the water level reached 5.8 cm below the soil surface and 0.8 cm above the soil surface for the II and the CF regimes, respectively. This condition occurred when precipitation was limited within this periods and minimum irrigation was supplied to the field.

The Excel Solver estimation was able to estimate all of the non-measurable variables with high accuracy shown as low cumulative error values of 1.61% and 0.54% for the II and the CF regimes, respectively (Table 1). The higher water input in the CF regime did not result in higher water consumption represented by crop evapotranspiration. Instead, this regime significantly increased the water loss through percolation by up to 24% (Table 1). Thus, the II regime can be considered as an alternative way to reduce percolation during the crop growth period, as also investigated in a previous study (Mao Zhi 1996). The percolation rate depends on the physical soil condition and it rate increases when the depth of water standing in the field increases (Toung and Bhuiyan 1999; Guerra et al. 1998; Kalita et al. 1992). The increasing standing water in the field will increase hydrostatic pressure, thus this situation stimulate downward movement of excess water in the soil to be percolation. Consequently, the CF regime with ponding water 2-5 cm in the field contributed to higher percolation rate compared to the II regime. Moreover, the CF regime also contributed to higher runoff significantly compared to the II regime (Table 1). These results suggested that the application of continuous flooding irrigation for irrigated rice was insufficient in water use because more excess water occurred through percolation and runoff.

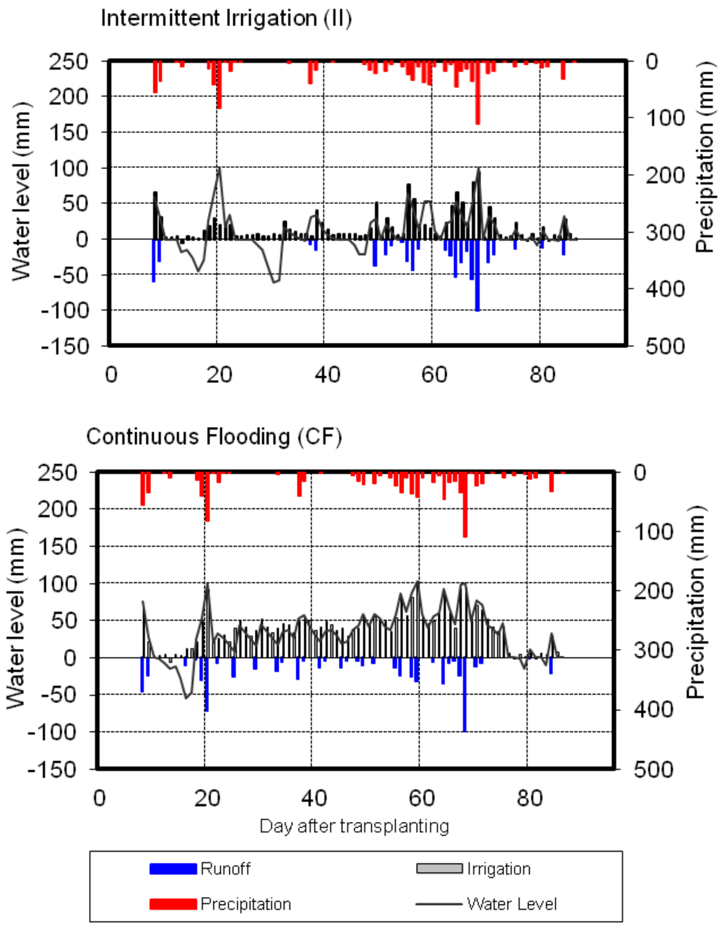

Figure.2 Water balance analysis for the irrigation regimes.

Table 1. Water balance components between the regimes

Water balance components	II regime	CF regime
Inflow:		
Precipitation (mm)	920±0a	920±0a
Irrigation water (mm)	289±32a	390±11b
Total Inflow (mm)	1209±32	1310±11
Outflow:		
Crop evapotranspiration (mm)	292±6a	290±5a
Runoff (mm)	808±34a	876±11b
Percolation (mm)	108±10a	143±1b
Total Outflow (mm)	1208±50	1309±17
Error between inflow and outflow (%)	1.61%	0.54%

the values showed the average ± standard deviation
a, b significant at $p<0.05$

3.2. Water use efficiency and productivity

Table 2 presents the water use efficiency index, water saving, and productivity in both irrigation regimes. It was clearly observed that the II regime can save a substantial amount of water, so the water use efficiency index can be increased significantly up to 37.6%. The higher value of the index was due to the minimum irrigation water in the II regime with comparable amounts of water consumption in both regimes (Table 2). Also, the excess water through percolation and runoff can be minimized by the application of the II regime. The increasing of water use efficiency index also was affected by high precipitation in the rainy season. Therefore, minimum irrigation water was needed especially for II regime. However, for the dry season with different pattern of precipitation and weather conditions, the increasing of water use efficiency index for II regime is probably different with the current values.

In addition, the current study revealed that water productivity for both regimes was not significantly different (Table 2). The comparable values of water productivity were caused by the comparable crop evapotranspiration and yield between the II and the CF regimes (Table 2). The comparable yield was obtained from the similar plant performances between the regimes, as shown in Table 3, which reveals no significant differences in plant height and number of tillers/hills during the crop season. The similar result was also reported by the previous study (Belder et al. 2004). They reported that during two rice seasons in China (1999 and 2000), there was no significant difference in yield between continuous flooding and intermittent irrigations.

Table 2. Water use efficiency and productivity for the irrigation regimes

Results	II regime	CF regime
Water Consumption (mm)	292±6a	290±5a
Yield (t/ha)	4.90±0.17a	4.87±0.31a
Water saving (%)	26.07%±6.12%	-
Water use efficiency index (kg/ha/mm)	1.72±0.19a	1.25±0.04b
Water Productivity (kg/m3)	1.68±0.034a	1.68±0.029a

the values showed the average ± standard deviation
a, b significant at $p<0.05$

Table 3. The average plant growth observation for both irrigation regimes

DAT	Plant height (cm)		ANOVA test	Number tillers/hill		ANOVA test
	II regime	CF regime		II regime	CF regime	
15	28.7	28.3	NS	3	3	NS
25	41.6	42.8	NS	12	12	NS
35	51.1	52.0	NS	39	35	NS
45	62.4	63.7	NS	44	45	NS
55	88.4	89.7	NS	48	46	NS
65	112.1	113.5	NS	38	34	NS
85	135.5	131.9	NS	35	31	NS

NS; not significant, SD: significant ($p < 0.05$)

As early mention, intermittent irrigation resulted in better yield and plant performances compared to continuous flooding irrigation even if not significant (Tables 2 and 3). The main reason is that under intermittent irrigation, aerobic condition was created. This condition promoted higher activity of the plants for the establishment of a larger and deeper root system (Uphoff and Kassam 2008). Also, this condition enhanced shoot activities when optimal water and oxygen available under intermittent irrigation (Yang and Zhang, 2010). These results suggested that intermittent irrigation is suitable way to increase water use efficiency without decreasing yield at the same time.

4. CONCLUSION

The main findings of this study were that intermittent irrigation (II) regime enhanced water use efficiency index significantly by up 37.6% in the rainy season. Also, this regime can save water input up to 26.07% compared to continuous flooding (CF) regime. The II regime reduced excess water through percolation and runoff significantly. The II regime also resulted in better yield and crop performance compared to CF regime even if not significant. The main reason is that under intermittent irrigation, aerobic condition was created. This condition promoted higher activity of the plants for the establishment of a larger and deeper root reported previous studies. Therefore, the results suggested that intermittent irrigation is suitable way to raise water use efficiency without decreasing yield for irrigated rice in Indonesia particularly in the rainy season. More experiments particularly in the dry season will be meaningful to examine water use efficiency index under II regime with different pattern of precipitation and weather conditions.

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