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WATER BALANCE ANALYSIS ON WATER MANAGEMENT OF ORGANIC SYSTEM OF RICE INTENSIFICATION (ORGANIC-SRI) IN WEST JAVA, INDONESIA

ANALISIS NERACA AIR PADA PENGELOLAAN AIR DALAM SYSTEM OF RICE INTENSIFICATION-*ORGANIK (SRI-ORGANIK) DI JAWA BARAT, INDONESIA*

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ABSTRAK

Penelitian ini dilakukan untuk menganalisa efektifitas irigasi berselang dengan neraca air pada lahan SRI dengan penerapan pupuk organik. Eksperimen dilakukan di Desa Gabus Wetan, Kab. Indramayu, Jawa Barat dari 17 November 2016 sampai 1 Maret 2017. Sensor parameter cuaca dan tanah dipasang di lahan untuk mendapatkan data harian kondisi lapang termasuk pertumbuhan tanaman. Data cuaca seperti hujan, suhu udara, kelembaban udara relatif, dan kecepatan angin dan kedalaman muka air diukur secara otomatis setiap 60 menit. Analisis neraca air dilakukan dengan kesalahan (error) yang rendah (1,00%) dimana jumlah air masuk melalui hujan dan irigasi sebesar 560 mm dan 865 mm, sedangkan jumlah air keluar melalui evapotranspirasi tanaman, perkolasi, dan limpasan berturut turut sebanyak 430, 306 dan 675 mm. Perbandingan dengan sistem pertanian konvensional dengan irigasi tergenang, menunjukkan bahwa produktivitas air dari SRI organik berturut turut 30% dan 27% lebih tinggi untuk produktivitas air berdasarkan jumlah air masuk dan evapotranspirasi. SRI organik juga memproduksi 33% produksi lebih tinggi dari sistem pertanian konvensional di lokasi yang sama. Kunci keberhasilan irigasi berselang adalah dengan menjaga tinggi muka air dipermukaan tanah (macak-macak) pada fase vegetatif dan generatif. Oleh sebab itu, cara ini merupakan alternatif pilihan bagi petani ketika sumber daya air berkurang karena perubahan iklim. Diseminasi hasil direkomendasikan melalui program pelatihan dan pendampingan bagi petani.

Kata Kunci: **SRI organik, pengelolaan air, neraca air, produktivitas, sistem monitoring**

ABSTRACT

The current study was carried out to analyze effectiveness of intermittent irrigation by water balance components in SRI paddy fields with organic fertilizer. The experiment was conducted in Gabus Wetan Village, Indramayu District, West Java, Indonesia from 17 November 2016 to 1 March 2017. Weather and soil sensors were set up in the fields to acquire data on daily field conditions as well as on plant growth. Data on weathers such as precipitation, air temperature, relative humidity, and wind speed were collected automatically during the season every 60 min, as well as the soil water depth. Analyzing the data collected, water balance analysis was well performed with low error (1.00%) in which the water inflows through precipitation and irrigation were 560 mm and 865 mm, respectively, while the outflows by crop evapotranspiration, percolation, and runoff were 430, 306 and 675 mm, respectively. Compared to conventional rice farming as commonly practices by applying continous flooding irrigation, water productivities of organic SRI were 30% and 27% higher with respect to total water input (WP_{IR}) and with respect to the amount of evapotranspiration (WP_{ET}, respectively. Organic SRI produced 33% higher yield than the average of conventional methods in the same subdistrict. The key was intermittent irrigation by maintaining shallow water depth (nearly soil surface) in the vegetative and generative stages. Therefore, it is an attractive option for farmers in irrigated areas where water resources are limited due to regional climate change effects. Disseminating the results through training and coaching programs for the farmers are fully recommended for near further activities.

Keywords: ***organic System of Rice Intensification, water management, water balance, productivity, monitoring system***

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I. INTRODUCTION

The System of Rice Intensification (SRI) was initially assembled in Madagascar in the early 1980s by Fr. Henri de Laulanié combining the transplanting of young, widely-spaced, single seedlings in a square pattern, with alternate wetting and drying, and with soil-aerating mechanical weeding of the fields in perpendicular directions -- he was using inorganic (chemical) fertilizer as that was widely believed to be necessary for getting good results (Stoop, 2011). When the government greatly reduced its subsidy for fertilizer in the late 1980s, and small, poor farmers could not afford to purchase it, organic fertilizer (decomposed rice straw and other vegetative matter) was introduced, and this proved to be successful. Therefore, organic fertilizers became generally recommended for SRI, although inorganic fertilization remained an option.

In Indonesia, where SRI has been introduced and demonstrated since 1999, there have been both organic and inorganic versions. SRI's alternative practices for rice farming have been disseminated to many provinces by several different programs conducted by government agencies and some NGOs. Based on data from the Ministry of Agriculture in 2014, it was reported that SRI had been demonstrated in 29 provinces and 247 districts with a total area of 450,855 ha. The Indonesian Government through different programs supports the application of SRI by providing assistance in the form of agricultural production inputs such as fertilizer, seed, irrigation pumps, hand tractors, and composting units (C. Arif, Setiawan, & Jatika, 2018). The increases in yield reported with SRI methods have had quite a wide range, affected at least in part by regional differences in climate and soils. Studies have indicated an average increase of 13% in Central Java (Nugroho *et al.*, 2018), 42% in demonstration fields in West Java (Gani, Kadir, Jatiharti, Wardhana, & Las, 2002) and 78% in Eastern Indonesia (Sato, Yamaji, & Kuroda, 2011).

However, since the availability of organic materials has been limited, and it was not easy for farmers to prepare and apply compost or manure, SRI has commonly been used with chemical fertilizers. Thus, two versions of SRI have developed in Indonesia (Sato *et al.*, 2011). First, a 'basic SRI' that applies some SRI elements such as young seedling, single transplanting, wider spacing, and soil-aerating weeding, with alternate wetting and drying, and some combination chemical and organic fertilization, applying as much organic matter as possible, often aiming for a 50-50 split. The second version, 'organic SRI' applies organic materials, compost or manure, rather than chemical fertilizer, to enhance biological activity in the soil and to improve its fertility over time. In general, the first version is more typically applied, while the application of organic SRI methods at field scale by farmers is limited.

In general, water management is also a constraint in disseminating SRI in Indonesia. It is not easy to apply intermittent irrigation within large irrigated areas, having the water level at the saturated level on a particular day and then to have the field in dried condition at other times instead of being continuously flooded. Although alternate wetting-and-drying (AWD) water management can save more water, however, weeds grow faster and become a problem for farmers, especially in the vegetative stage. So, the farmers remained use continous flooded irrigation even with SRI principles (for crop managements).

Even though SRI trials and demonstrations produced impressive results in terms of productivity, many farmers remained skeptical about this water management (Chusnul Arif, Setiawan, & Sutardi, 2017). As previously mention, the farmers prefer to apply flood irrigation, not only to reduce weed growth but also to avoid water shortages due to the unreliable water supply system. Farmers do not understand that continuous flooding causes rice plant roots to degenerate from hypoxia and that rice plants become more vulnerable to subsequent water stress, not able to take advantage of water reserves in the lower soil horizons when their roots die back and become ineffective.

The practice of continuous flooding is very inefficient, supplying much more water than the plants' actual requirements and also emitting large volumes of greenhouse gas emissions (Hadi, Inubushi, & Yagi, 2010; Utaminingsih, Soentoro, Winskayati, & Irianto, 2017). Also, this method has water losses from deep percolation, seepage through bunds, and runoff from the soil surface (Bouman, 2001). This entails the loss of nutrients from the field and/or the pollution of groundwater supplies to the extent that inorganic fertilizers and agrochemicals are applied.

In addition, there is limited information on the application intermittent irrigation with organic SRI farming. Therefore, it is important to observe intermittent irrigation of SRI farming with organic nutrient management and compare it to flooded irrigation. Fully organic SRI experiments were conducted in collaboration with a local farmer who had been trained at an Organic SRI Center in West Java. For these experiments, intermittent irrigation was applied instead of continuous flood irrigation to save water input. The main objective of this study was to analysis the effectiveness of intermittent irrigation with organic application by performing water balance analyses to observe the water use efficiency and productivity of organic SRI.

II. METHODOLOGY

2.1. Field Experiments and Methodology

One rice season was studied in Gabus Wetan village, Indramayu District, West Java, Indonesia during the period 17 November 2016 to 1 March 2017 (Figure 1). Local variety of rice (*Oryza sativa* L), Ciherang, was cultivated with basic SRI practices: young seedlings (transplanting at 14 days after sowing) and one plant per hill (transplanting single seedlings) with wider spacing of 30 cm × 30 cm. Organic fertilizer (compost) was used with a quantity of 7 ton/ha and organic liquid fertilizer was applied with doses of 200 l/ha. Weeding was conducted regularly every ten days until 40 days after transplanting with a mechanical weeder. Irrigation water was procured from a small pond nearby, having abundant water hyacinth (*Eichhornia crassipes*) (Figure 2).

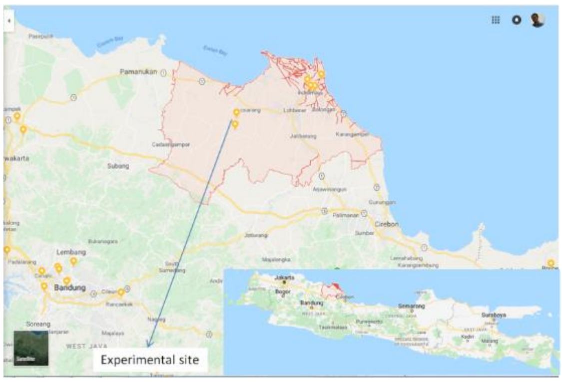

Figure 1 Maps of Experimental Site in Indramayu District, West Java, Indonesia

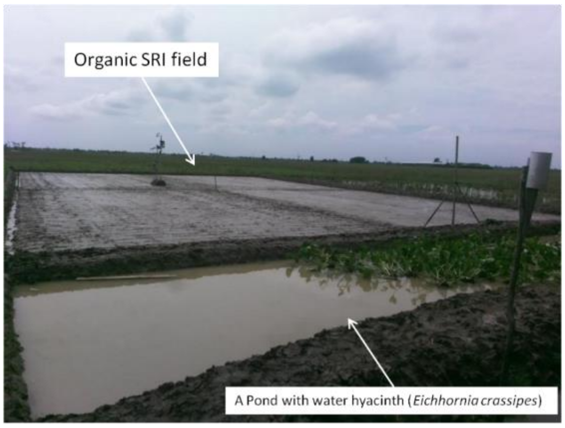

Figure 2 Organic SRI Field with a Pond Containing Water Hyacinth (*Eichhornia crassipes*)

Flowchart of the methodology can be reffered to Figure 3. Some primary data were observed, such as weather, soil and plant performance. Based on weather data, reference evapotranspiration (ETo) then calculated. Afterwards, water balance analysis was performed using observed data and crop coefficient (Kc) to estimate irrigation water, runoff, percolation, crop evapotranspiration by MS Excel Solver. Lastly, water productivity and water application efficiency based on estimated irrigation water and crop yield.

2.2. Field Measurements

Weather parameters such as air temperature (Ta), relative humidity (RH), solar radiation (Rs), and wind speed (u) were measured every 30 minutes using a Davis Vantage Pro2 Weather Station (Davis Instruments Corp, USA) as well as precipitation. Based on those weather parameters, reference evapotranspiration was then calculated daily according to the Hargreaves model (Wu, 1997). Water depth was measured by the pressure sensor, CTD (Decagon Devices, Inc, USA) at 30-minute intervals. The sensor was kept in the perforated PVC pipe located in the middle of the field.

Plants growth performance was measured every week for their height and tiller number. At harvesting time, 20 hills were selected for a random sample and were measured for their height, tillers, panicles, root length and weight. After measuring the fresh weight, the numbers of spikelets were counted by separating panicles from the plants. Yield measurement was then taken, and it was compared with flood-irrigation yields in the nearest location as well as with other measures of plant performance.

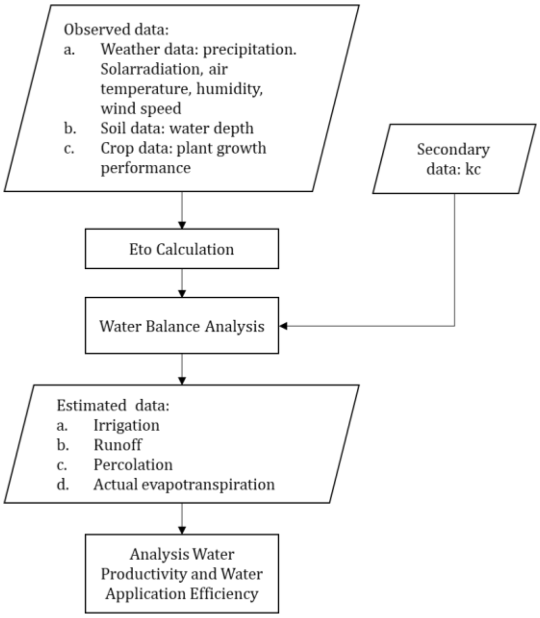

Figure 3 Flowchart of the Methodology in this Research

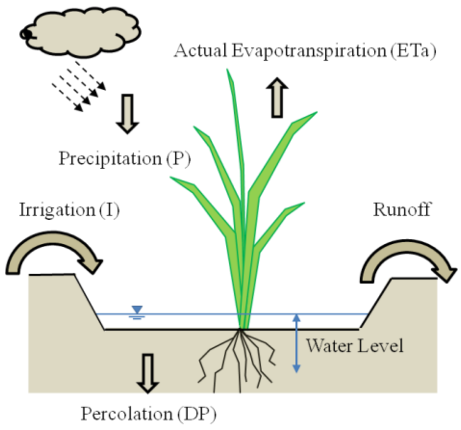

Figure 4 Water Balance Schema in The Field

2.3. Water Balance Analysis

Water balance components were analyzed according to Figure 4. Water input (inflow) consisted of precipitation and irrigation, while actual evapotranspiration, runoff, and percolation were considered as the water output (outflow). Accordingly, the water balance equation was defined as follows:

$$\mathrm{WL}(i) = \mathrm{WL}(i-1) + P(i) + I(i) - (\mathrm{ETa}(i) + Q(i) + \mathrm{DP}(i)) \quad (1)$$

where WL is water depth (in mm), P is precipitation (in mm), I is irrigation (in mm), ETa is actual evapotranspiration (in mm), Q is runoff (in mm), DP is percolation (in mm), and i is time (on a daily basis). Here, runoff was defined as horizontal water outflow through overbund flow and bund cracking (seepage). Excel Solver was used to estimating non-measured components by minimizing the following objective function:

$$F = \sum_{t=1}^{n} |\mathrm{WL}_o(i) - \mathrm{WL}_m(i)| \quad (2)$$

where WL_o is the observed water level (in mm) and WL_m is estimated water level by Excel Solver (in mm). Excel solver was performed by the following constraints:

$$\mathrm{Kc}_{min} \leq \mathrm{Kc}(i) \leq \mathrm{Kc}_{max} \quad (3)$$

$$I(i) \geq 0; \mathrm{Qr}(i) \geq 0; \mathrm{DP}(i) \geq 0 \quad (4)$$

where, Kc_{min} is the minimum crop coefficient, Kc_{max} the is maximum crop coefficient, and Kc is the estimated crop coefficient. Kc_{min} and Kc_{max} were determined according to FAO's standard values. Kc value was used to determine Crop Evapotranspiration (ETc) by the following equation:

$$\mathrm{ETc}(i) = \mathrm{Kc}(i) \times \mathrm{ETo}(i) \quad (5)$$

where ETo is the reference evapotranspiration (in mm) according to the Hargreaves model (Wu, 1997). The estimation process was performed four times in each growth stage, i.e., the initial, crop development, mid-season, and late-season stages (Chusnul Arif, Setiawan, Mizoguchi, & Doi, 2012; Chusnul Arif *et al.*, 2012). ETc was used as initial condition for ETa that will be estimated. Then, percentage error estimation was defined as follow:

$$Error = \frac{\sum(I_{nf} - I_{nf})}{\sum I_{nf}} \quad (6)$$

Where, I_{nf} is total inflow (precipitation and irrigation), and O_{nf} is total outflow (crop evapotranspiration, runoff and percolation).

Then, water use efficiency was represented in terms of water application efficiency (EA) that is calculated based on the following equation (Bouman, Peng, Castañeda, & Visperas, 2005):

$$\mathrm{EA} = 100x \frac{\sum \mathrm{ETc}}{\sum(I+P)} \quad (7)$$

Following (Bouman *et al.*, 2005), there are two kinds of the definition of water productivity; first, water productivity defined as total yield per total water evaporated and transpirated (WP_{ET}) and total yield per total water input (WP_{IR}) by the next equations:

$$\mathrm{WP}_{\mathrm{ET}} = \frac{Y}{\sum \mathrm{ET}_c} \quad (8)$$

$$\mathrm{WP}_{\mathrm{IR}} = \frac{Y}{\sum P+I} \quad (9)$$

Where, WP_{ET} and WP_{IR} in g grain/kg water and Y is yield (ton/ha). As a comparison, continuous flooding irrigation which commonly applied by the local farmers. In this regime, the water level was commonly kept at 5 cm depth (from the soil surface) from initial to the end of mid-season stages, and then in water was drained in the late-season stage. The productivity of conventional rice farming was determined based on the average yield in the subdistrict of Gabuswetan.

III. RESULTS AND DISCUSSION

3.1. Weather Conditions

The daily average of maximum (T_{max}), average (T_{ave}) and minimum (T_{min}) air temperatures is shown in Figure 5 as well as relative humidity (RH). Those weather data having fluctuating. For air temperature data, the trend showed relatively constant. On the other hand, the trend of relative humidity was slightly increased. Th maximum air temperature was in between 26.27 – 33.77°C, while its minimum ranged was on 22.37 – 25.33°C. Meanwhile, during planting season the average air temperature was 26.99°C. Relative humidity negative correlation to air temperature in which driest condition occurred on 21 December 2016 with RH of 78% and the maximum air temperature was 33.33°C. On the other hand, the wet condition on 11 February 2017 with RH of 97% and the average air temperature was 24.39°C.

Figure 6 shows the total solar radiation and reference evapotranspiration during the planting period. The Hargreaves model of reference evapotranspiration was calculated based on air temperature and solar radiation (Wu, 1997), and they have a positive correlation to both parameters, so the trend both solar radiation and reference evapotranspiration was similar as shown in Figure 6. The maximum solar radiation occurred on 5 February 2017 when its total value was 20.72 MJ/m²/d. In this day, total reference evapotranspiration was also maximum value with a total of 5.22 mm. The minimum solar radiation was 4.24 MJ/m²/d and it caused minimum reference evapotranspiration of 0.99 mm.

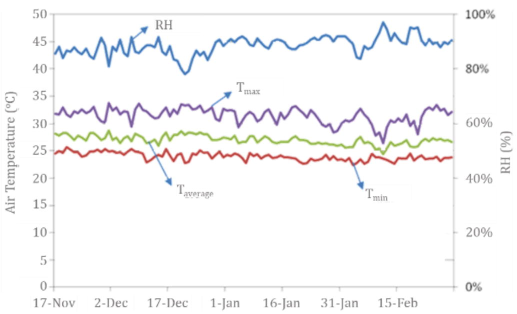

Figure 5 Air Temperature and Relative Humidity During the Planting Period

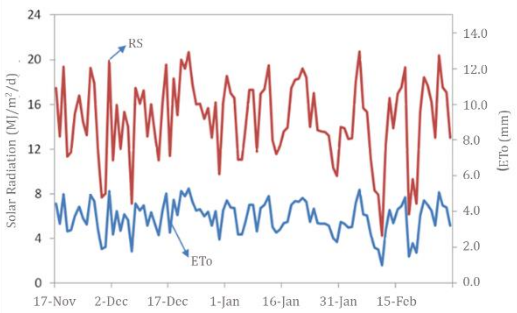

Figure 6 Solar Radiation (Rs) and Reference Evapotranspiration (ETo) During the Planting Period

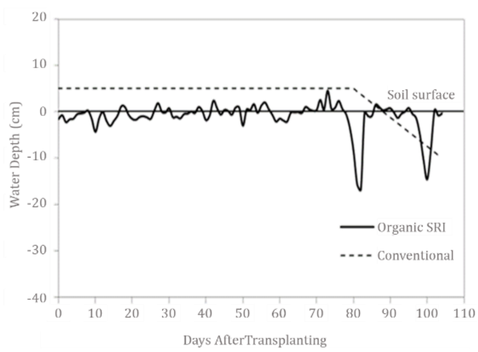

Figure 7 Daily Mean Water Depth (Water Level) of Organic SRI and Conventional Rice Farming

3.2. Hydrological Conditions

During the planting season, comparison between daily average water depth of organic SRI and conventional fields can be referred to Figure 7. The daily mean water depth in the organic SRI field was nearly at the soil surface (0 cm) or even a little lower than the soil surface during 0-70 days after transplanting (DAT). This condition occurred from vegetative (initial and crop development stages) to early generative stages (mid-season stage); then from 10 days onward (70-80 DAT), a thin water layer of 0-2 cm was maintained after panicle formation. Meanwhile at the same time (initial to the end of mid-season stages), the conventional rice farming field was intended to be kept continuously flooded (5 cm above soil surface). However, the water level in organic SRI Field has fluctuated and at particular times became below the soil surface when water was lost by cracking in the bunds or there was runoff and by percolation. Finally, water was drained at the late-season stage during 80 – 93 days after transplanting (2 weeks before harvesting/late season stage).

For SRI application in the field, it is recommended to keep soil in wet condition but not submerged by draining water shortly after the transplanting, i.e., during the vegetative stage, and then maintaining thin water layer after panicle formation as conducted in this study (Uphoff, Kassam, & Harwood, 2011). It is also recommended to maintain the water level close to the soil's surface as best the water management practice for SRI in term of producing more yield and having a minimum negative environmental impact in terms of greenhouse gas emission (Setiawan *et al.*, 2014).

However, having a lower water depth (near the soil surface) in the early vegetative stage makes weed growth faster, thus there is more need for labor to control it. On the other hand, when rice is grown under continuously flooded conditions, such as in conventional rice fields, this makes weed control easier or even unnecessary, thereby saving labor (McHugh, Steenhuis, Barison, Fernandes, & Uphoff, 2002).

For areas with limited water resources, continuous flooding in conventional rice field will a problem since they need more water for irrigation (Table 1). In this study, it was found that the conventional field needs at least 12% more water.

Percentage error estimation of water balance components were 1.00% and 2.19% for the organic SRI and conventional fields, respectively, as shown in Table 1. It is indicated that the estimation method used was reasonably accurate to estimate water balance components. Here, it was found that water loss through runoff was dominant in both organic SRI and conventional fields, accounting for approximately 48% and 38% of the total outflow, respectively.

In addition, submerged soil condition increased water loss through percolation in the conventional field (Table 1). Flooding irrigation drained 58.7% more percolation water than organic SRI Field. This occurred possibly by increasing hydrostatic pressure that will stimulate the downward movement of excess water in the soil (Bouman & Tuong, 2001).

3.3. Water Use Efficiency and Productivity

Organic SRI methods produced 33% higher yield than that from the average of conventional rice cultivation in the same subdistrict as given in Table 2. The better yield of organic SRI under aerobic soil conditions suggested that this condition was ideal to promote the higher metabolic activity of the plants for establishing larger and deeper root systems as earlier mentioned. This is supported by (Barison & Uphoff, 2011) who observed increasing in nutrient uptake with SRI farming due to deeper and greater root formation and growth in all the crop cycle. On the other hand, conventional rice farming induced shallower and shorter in root growth under submerged conditions, when roots die back because of hypoxia.

Also, this condition enhanced shoot activities when available water and oxygen were optimal for the plant (Yang & Zhang, 2010). In this study, the probable key of success in higher yield was thin water level during the crop development stage (vegetative phase) that increased the number of panicles, which would have resulted from promoted more tiller development as reported in a previous study (Nugroho *et al.*, 2018).

Water productivity of organic SRI was also higher than that of conventional cultivation, both with respect to total water input (WP_{IR}) and with respect to the amount of evapotranspiration (Table 2). Under intermittent irrigation, WP_{IR} and WP_{ET} were 0.54 and 1.80 g grain/kg water, respectively.

Their values were 30% and 27% more than those values for conventional production. The same results also observed by the previous study that reported SRI farming increased water productivity from 0.82 to 1.12 g/kg (Fuadi, Purwanto, & Tarigan, 2016).

In addition, SRI farming had higher water productivity than Integrated Crop Management (ICM) (Subari, Joubert, Sofiyuddin, & Triyono, 2012). Higher water productivities in organic SRI indicated that intermittent irrigation was a more effective water use to produce more rice. These results were confirmed by previous study that reported intermittent irrigation raised the water use efficiency index by 38% by saving water input by 26% compared to conventional rice farming and also raising yield (Chusnul Arif, Setiawan, Sofiyuddin, & Martief, 2013). Therefore, intermittent irrigation with organic SRI be a promosing option to the farmers in irrigated areas where water resources to be scarce and limited because regional climate-change effects. However, farmers should do more intensive work in the field to control weeds particularly in the early vegetative stage.

Table 1 Seasonal Water Inflow and Outflow of Organic SRI and Conventional Rice Farming

Parameters	Rice Farming	
	Organic SRI	Conventional
Inflow:		
Precipitation (mm)	560	560
Irrigation water (mm)	865	967
Total Inflow (mm)	1425	1527
Outflow:		
Runoff (mm)	675	563
Crop Evapotranspiration (mm)	430	446
Percolation (mm)	306	485
Total Outflow (mm)	1411	1494
Error (%)	1.00%	2.19%

Table 2 Yield, Water Efficiency and Productivity of Organic SRI and Conventional Rice Farming

Parameters	Rice Farming	
	Organic SRI	Conventional
Yield (ton/ha)	7.74	5.09
EA (%)	30.06%	29.17%
WP_{ET} (g grain/kg water)	1.80	1.31
WP_{IR} (g grain/kg water)	0.54	0.38

IV. CONCLUSIONS

Water balance analysis was well performed in the organic SRI field under intermittent irrigation as indicated by the low percentage error. According to the analysis, water inflows through precipitation and irrigation were 865 mm and 560 mm, respectively, while outflows by crop evapotranspiration, percolation, and runoff were 430, 306 and 675 mm, respectively. Compared to conventional rice farming, water productivities of organic SRI were 30% and 27% higher for water productivity with respect to total water input (WP_{IR}) and with respect to the amount of evapotranspiration (WP_{ET}), respectively. Organic SRI produced 33% higher yield than conventional methods. Therefore, it is a promosing option for the farmers in irrigated areas where water resources to be scarce and limited because of regional climate-change. Disseminating the results through training and coaching programs for the farmers are fully recommended for near further activities.

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