A water recirculation system for the cultivation of *Oryza sativa* L. at Sumedang, Indonesia

E. Widiasri[1], B.K. Gaib[1], D. Karnia[1], R.J. Putri[1], I.C. Adilaksono[1], D. Nofitasari[1], R. Manurung[1] and M.Y. Abduh[1,*]

[1] School of Life Sciences and Technology, Institut Teknologi Bandung, Jawa Barat 40132, Indonesia

* Corresponding author: yusuf@sith.itb.ac.id

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ABSTRACT

The influence of water input and recirculation systems towards biomass production of Ciherang paddy was investigated. Sixteen containers containing the seedlings of Ciherang paddy (age of 9 days) were cultivated in a screen house at Jatinangor with the irradiance of 9–14 MJ/m^2, the temperature of 27–29°C, the relative humidity of 72–75%, and the wind speed of 0.4–0.6 m/s. The plants were subjected to 5 different treatments; P0 and PI: without water recirculation and a 50% shading net with a different water input of 1,200 mL/day for P0 and 810 mL/day for PI, PII: without water recirculation and with a 50% shading net and water input of 750 mL/day, PIII: with water recirculation and with a 50% shading net and water input of 1,500 mL/day, and PIV: without water recirculation and a 50% shading net but with additional air circulation and additional humidity and water input of 800 mL/day. After 114 days of cultivation, the plants were harvested and analyzed in terms of rice growth, productivity of rice biomass, nitrogen content in the biomass, and evapotranspiration rate. At the end of the cultivation period, the best results were obtained for PIII with an average plant height of 103 cm, 131 leaves, 36 tillering, and 29 panicles/plant. The average water holding capacity for PIII varies from 553–4,532 mL with an average evapotranspiration rate of 93–253 mL/day. The plant biomass was 276.1 g on a dry basis with a water content of 38.9% and total nitrogen content of 3.2 g, with an estimated rice productivity of 0.11 kg/m^2. The average amount of excess water for the recirculation system was 1,086 mL/day and the total nitrogen content in the excess water was 6 mg/day.

Keywords: Paddy, water input, recirculation system, shade net, productivity

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INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple food for more than half of the world's population with global productivity of 518 million tons every year (Vijayakumar *et al*., 2006). One of the major constraints in the cultivation of paddy is sufficient water for irrigation. The total water input in paddy fields varies between 500 and 3,000 mm of irrigation depths depending on the environmental conditions and lengths of the growing period (Bouman and Tuong, 2001). Currently, the cultivation of paddy still uses a lot of water to flood paddy fields that causes high water losses through evaporation, seepage, and percolation (Vijayakumar *et al*., 2006; Satyanarayana *et al*., 2007; Chapagain and Yamaji, 2010; Thakur *et al*., 2010; Uphoff *et al*., 2011). A limited amount of irrigation water available for agriculture may affect the production of rice (Bouman, 2007), particularly in Asia because its cultivation of paddy uses more than 90% of total water for irrigation (Khepar *et al*., 2000).

According to Cabangon *et al*. (2001), 15 million ha of irrigated paddy area in Asia may experience physical scarcity of water and approximately 22 million ha of irrigated dry-season rice may suffer economic water scarcity by 2025. To overcome this potential threat, an alternative cultivation system of paddy that requires less water is required. The crucial challenge for sustainable rice production is to decrease the amount of irrigation water while increasing or at least maintaining the paddy yield to meet the global demand by improving water use efficiency (Yang and Zhang, 2010). According to Hill *et al.* (1991), recirculating tailwater recovery systems for rice production can facilitate the use of drainage water. The advantage of such a system includes the containment of tailwater and pesticide residues, the best water management facility, and reduction of operational cost. Miskam *et a*l. (2013) has designed a laboratory-scale automatic system for irrigation and drainage of paddy. The system automatically controls the water level in the system but no quantitative data on the productivity of rice and water use efficiency have been reported.

Various studies on water-saving technologies for the cultivation of paddy have been carried out for the past decades such as alternate wetting and drying (Bouman and Tuong, 2001; Belder *et al*., 2004), direct dry seeding (Tabbal *et al*., 2002), saturated soil culture (Belder *et al*., 2004), and aerobic rice culture (Bouman *et al*., 2005; Kato *et al*., 2009). A system of rice intensification (SRI) also had been developed that involves minimum daily application of water or alternately wetting and drying the paddy field increased the rice yield by 25–70% while reducing water requirement up to 28% (Satyanarayana *et al*., 2007; Uphoff *et al*., 2011; Nyamai *et al*., 2012; Thakur *et al*., 2014). Although the amount of water input for the cultivation of paddy has been successfully reduced, systematic studies that report on potential recirculation of the irrigation water are still very scarce. The water that remains in the paddy field still contains a considerable amount of nutrients that can be recirculated back to the field to reduce the amount of water and fertilizer input and consequently reduce the production cost of rice. Hence, this study was carried out to investigate the effect of the water-recirculation system on the number of leaves, weight and height of plant, number of tillers, and number of panicles as well as the nitrogen content in the biomass and evapotranspiration rate. In addition, the effects of the initial amount of water input, light intensity as well as air recirculation system during the cultivation period were also observed.

MATERIALS AND METHODS

The seedlings of *Oryza sativa* L. var. Ciherang was used. The soil was obtained from a local store in Sumedang, West Java, Indonesia. In addition, commercial compost was used and purchased from a local store in Bandung, West Java, Indonesia.

Cultivation of Paddy

The cultivation of *Oryza sativa* L. var. Ciherang was conducted in containers (diameter: 30 cm, height: 40 cm) under various cultivation conditions as shown in Table 1 and Figure 1 at the Technical Laboratory IA, Institut Teknologi Bandung, Jatinangor Campus, Sumedang, West Java, Indonesia. Every cultivation condition was replicated four times and average values were reported. One paddy seedling (9 days after planting) was planted in each container that already contains soil and compost (1:1 ratio) as the growing media. The bottom part of the container was perforated (five spots) as an outlet path for excess water that passed through the growing media due to the percolation process. In addition, a vessel was placed under each pot to collect the excess water. Each cultivation condition was conducted inside a small screen house. All sides of the screen house except the left and right sides were covered with transparent plastic to protect from the rainwater. The watering schedule of the plants was performed every day during the cultivation period, with a watering rate of 5 mL/s. The cultivation was carried out for 116 days. The height of paddy and the number of tillers were observed only during the growing period and became approximately constant after approximately 75 days of planting. The number of leaves was determined for 52 days before the values became approximately constant. As the plant entered the generative phase, the number of panicles was observed starting from day 52 up to 110 days after planting. The excess water, water holding capacity and evapotranspiration rate were determined throughout the cultivation period of 116 days.

Table 1 Cultivation conditions of *Oryza sativa* L. var. Ciherang

Cultivation conditions	Description
P0	Water input: 1,200 mL/day, without water recirculation, without a 50% shading net
PI	Water input: 810 mL/day, without water recirculation, without a 50% shading net
PII	Water input: 750 mL/day, without water recirculation, with a 50% shading net
PIII	Water input: 1,500 mL/day, with water recirculation, with a 50% shading net
PIV	Water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

For the cultivation condition of P0, a water input of 1,200 mL/day was set based on the recommended irrigation water for paddy which is 20,000 m^3/ha/harvest (Solh, 2002), while a water input of 810 mL/day without water recirculation and a 50% shading net was set for PI. For cultivation conditions of PII and PIII, a shade net of 50% coverage was installed inside the screen house. For the cultivation condition of PIII, excess water that was drained through the bottom part of the container was collected daily and added with additional tap water before being recirculated back to growing media. As for the cultivation condition of PIV, holes were created at the front and the tip-top part of the plastic cover to provide circulation of air. A water-filled container (length: 60 cm, width: 90 cm, height: 38 cm) was also placed inside the screen house to provide additional humidity so that the cultivation condition resembles the condition of a coastal area.

Data Measurement

The parameters for physiological growth of paddy particularly plant height, number of leaves, number of tillers, and number of panicles were measured daily throughout the cultivation period. Excess water was measured daily based on the volume of water that was drained through the bottom part of the pot. The microclimates of cultivation conditions such as temperature, relative humidity, solar irradiance, and wind velocity were measured twice a day (08.00 and 16.00). Temperature and relative humidity were measured by using a whirling hygrometer (HTC 2, China). Solar irradiance was measured by using a solar power meter whereas the wind velocity was measured by using a digital anemometer (Vernier, USA). The nitrogen content in the harvested biomass was measured by using a Kjeldahl method (Jones, 1991). The measurement was performed at Raksa Buana Analytical Chemistry Laboratory (Bandung, West Java, Indonesia).

Data Analysis

The evapotranspiration rate was calculated using the Penman-Monteith equation (Solh, 2002) as shown in equations (1) and (2).

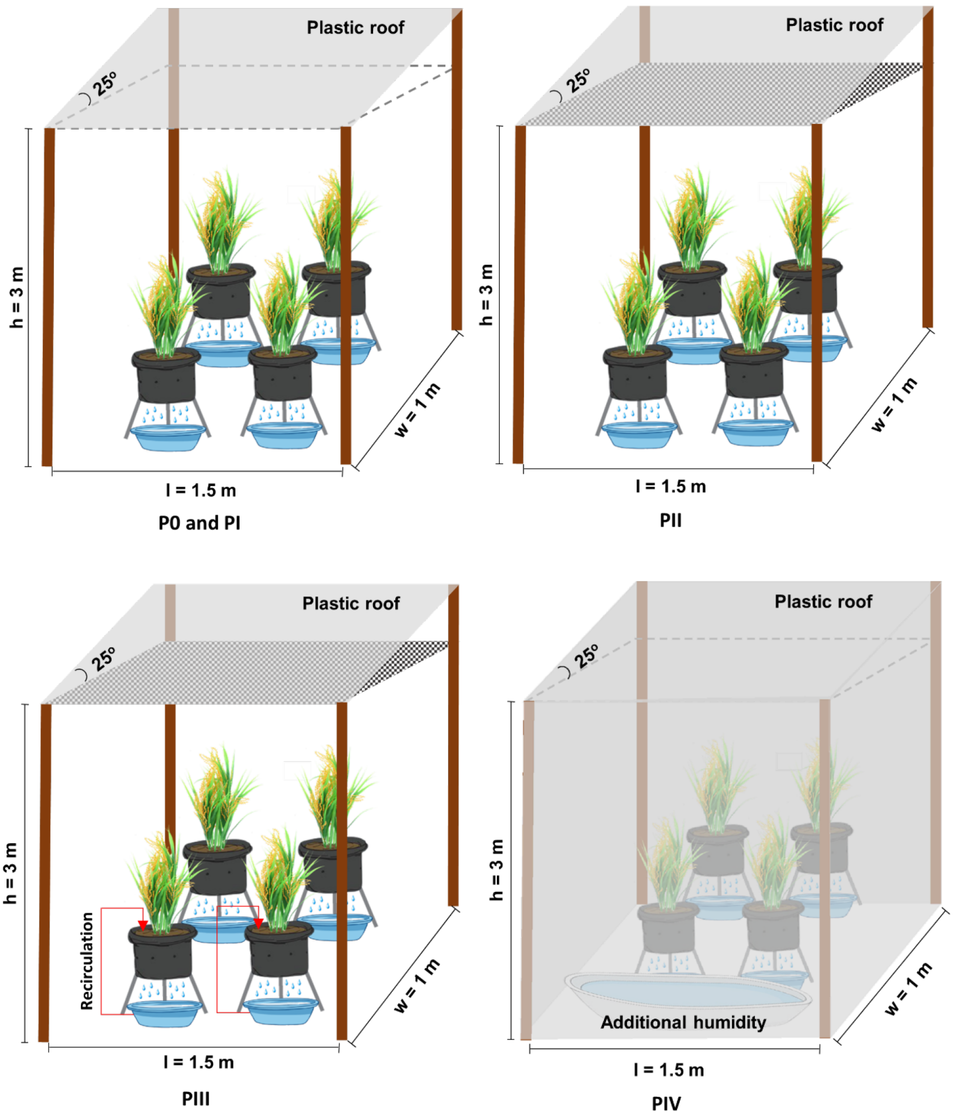

Figure 1 Cultivation conditions of *Oryza sativa* L. var. Ciherang rice at Jatinangor, Sumedang. P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273} U_2(es^o - e_a)}{\Delta + \gamma(1 + C_d U_2)} \quad \text{------- (1)}$$

$$ET_{crop} = ET_0 \cdot K_c \quad \text{-------- (2)}$$

where ET_o is the potential evapotranspiration rate (mm/day), R_n is the net irradiance (MJ/m^2/day), G is the heat transfer to soil (MJ/m^2/day), C_n is a numerator constant (900), U_2 is the wind velocity (m/s) at an elevation of 2 m above the ground, es^o is the saturated vapor pressure (kPa), e_a is the actual vapor pressure (kPa), C_d is a denominator constant (0.34), γ is a psychometric constant, Δ is the difference of vapor pressure curve (kPa/°C), T is the temperature (°C), ET_{crop} is the actual evapotranspiration rate (mm/day), and K_c is the plant coefficient. The calculated evaporation rate was multiplied with the surface area of the container (0.07065 cm^2) to get the evapotranspiration rate in mL/day.

Water holding capacity that indicates the amount of water that can be accumulated by the growing media was calculated using equation (3).

$$WHC = (WI – EW) + (Acc – ET_{crop}) \quad \text{------- (3)}$$

where WHC is the water holding capacity (mL/day), WI is the water input (mL/day), EW is the excess water (mL/day), Acc is the water that accumulated in the container the day before (mL/day) and ET_{crop} is the actual evapotranspiration rate (mL/day).

The wet and dry weight of rice roots, wet and dry weight of stems, weight of dry-milled, and dry-harvested grains were measured by using an analytical balance (Precisa, Swiss) at the end of the cultivation period (116 days after planting). The dry weight was obtained after the samples were dried by using an oven (Heratherm, Thermo Scientific, USA) at 60°C for 48 hours until the weight was constant. The moisture content of samples was calculated according to equation (4).

$$\text{Moisture content (\%)} = [(ww – dw)/ww] \times 100 \quad \text{------ (4)}$$

where ww and dw are wet weight (g) and dry weight (g) of the samples, respectively.

The productivity of milled grain for each cultivation condition was estimated by dividing the dry weight of milled grain with the cultivation area as shown in equation (5) whereas productivity of rice was estimated from equation (6).

Productivity of milled grain (kg/m^2) = Dry weight of milled grain (kg) / A (m^2) ------- (5)

where A is the area of the container used for the cultivation of paddy (0.36 m^2).

Productivity of rice (kg/m^2) = Productivity of milled grain (kg/m^2) × Filled grain (%) ------- (6)

All the analyses were performed in triplicate and expressed as mean and standard deviation. Differences were tested with a one-way analysis of variance using MINITAB 17.

RESULTS AND DISCUSSION

Effect of Cultivation Condition on Crop Growth

The microclimate conditions particularly solar irradiance, temperature, humidity, and wind velocity for all cultivation conditions are shown in Table 2. Temperature and humidity for all cultivation conditions are approximately the same which lies in the range of 27.4–28.6°C and 72.0–75.1%, respectively. The values are within range for optimum temperature (24–29°C) and relative humidity (33–90%) for the cultivation of paddy (Dash and Dash, 2009). The average solar irradiance measured in this study lies in the range of 9.1–13.8 MJ/m^2. The solar irradiance was slightly lower for PII and

PIII because a 50% shading net was used in those areas and consequently reduced the intensity of light received inside the screen house by about 20–34%. The maximum solar irradiance was recorded when no shading net was used. However, the value was still lower than a solar irradiance of 14.9 MJ/m^2 recorded by Jing *et al*. (2009). As such may be due to the use of plastic material on the roof of the screen house used in this study. Temperature, humidity, and wind velocity were not significantly different among different treatments, whereas the solar irradiance was significantly different among different treatments ($P < 0.0001$).

Table 2 Microclimate conditions for the cultivation of *Oryza sativa* L. var. Ciherang rice at Jatinangor, Sumedang

Microclimate factors	Cultivation conditions				
	P0	PI	PII	PIII	PIV
Solar irradiance (MJ/m^2)	13.8 ± 0.7	13.6 ± 0.4	9.1 ± 1.6	10.3 ± 0.9	11.4 ± 1.7
Temperature (°C)	27.8 ± 1.5	28.0 ± 1.5	27.4 ± 1.3	27.6 ± 1.4	28.6 ± 1.5
Humidity (%)	73.0 ± 6.4	73.0 ± 6.8	72.0 ± 6.4	72.8 ± 6.2	75.1 ± 6.9
Wind velocity (m/s)	0.56 ± 0.1	0.55 ± 0.1	0.53 ± 0.1	0.59 ± 0.1	0.40 ± 0.1

Note: P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

Figures 2A–D shows the effect of the water-recirculation system on plant height, number of leaves, number of tillers, and number of panicles. The best results were obtained when the screen house was covered with a 50% shading net (solar irradiance of 10.3 MJ/m^2) and the plants were given a water input of 1,500 mL/day and the excess water was being recirculated back to the plants (PIII). At the end of the cultivation period at such conditions, the average height of the plants was 103 cm with an average of 131 leaves, 36 tillering, and 29 panicles per plant. The results are better as compared to other conditions because the plants received the highest water input to ensure the wetness of the growing media. In addition, the nutrients in the excess water were being recirculated back to the growing media daily. Thus, the recirculated system applied in PIII could preserve the amount of nutrients in the growing media to promote plant growth. In contrast, excess water in other conditions was not being recirculated back to the plants.

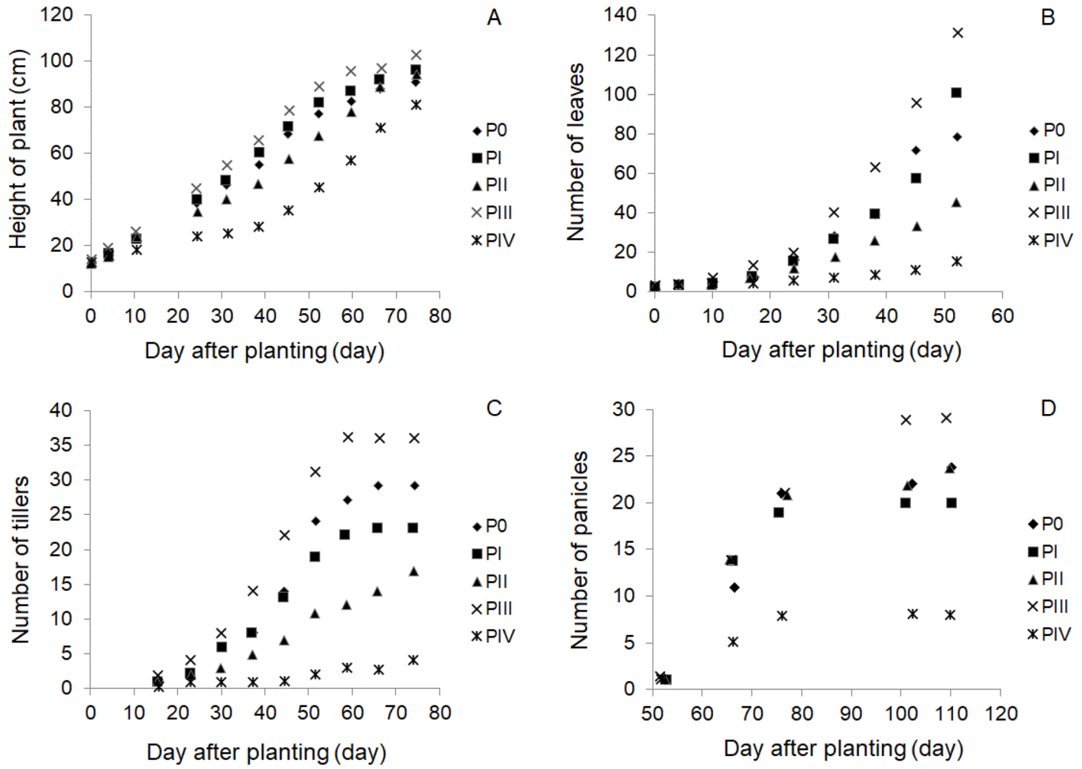

Figure 2 The height of paddy (A), number of leaves (B), and number of tillers (C) during the growing phase, and number of panicles during the generative phase of *Oryza sativa* L. var. Ciherang rice at different cultivation conditions at Jatinangor, Sumedang. P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

The nitrogen content in the excess water was determined and the results are shown in Table 3. The amount of excess water for each cultivation condition highly depends on the amount of water input and packing density of the media. When the plants were given a water input of 1,500 mL/day (PIII), approximately 72.4% of the water input was able to flow through the bottom holes of the container. The excess water had a nitrogen concentration of 5.5 mg/L and was being recycled back to the plant which resulted in an addition of around 6 mg nitrogen/day to the plants. Thus, the recirculation system of excess water in PIII ensures that the 6 mg of leached nitrogen in excess water was being recycled back to the growing media for plant growth. Therefore, the PIII cultivation condition had more available nitrogen content in the growing media compared to other cultivations conditions.

Table 3 Availability of nitrogen in the excess water at different cultivation conditions

Parameters	Cultivation conditions				
	P0	PI	PII	PIII	PIV
Water input (mL/day)	1,200 ± 6	810 ± 5	750 ± 4	1,500 ± 6	800 ± 5
Excess water (mL/day)	767 ± 59	518 ± 49	449 ± 44	1,086 ± 62	608 ± 50
Nitrogen concentration (mg/L)	7.4 ± 0.4	8.3 ± 0.3	10.2 ± 0.7	5.5 ± 0.1	7.3 ± 0.4
Nitrogen amount (mg/day)	5.7 ± 0.02	4.3 ± 0.01	5.1 ± 0.03	6.0 ± 0.01	4.5 ± 0.02

Note: P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

Nitrogen is one of the macronutrients required for the growth of paddy and has an essential role to maintain the cultivation of paddy (Spiertz, 2010; Sinclair and Rufty, 2012). According to Manzoor *et al*. (2006), plant height, number of tillers, and number of panicles are significantly promoted by higher nitrogen content in a growing media. In addition, a sufficient amount of nitrogen had been reported to promote better growth of paddy and be able to accelerate the tillering (Tanaka and Garcia, 1965; Stutterheim and Barbier, 1995; Mae, 1997). As for PI, PII, and PIV, the percentage of excess water that was able to be contained varies from 56–76% which may be due to the packing density of the media. The excess water obtained from P0, PI, PII, and PIV had a nitrogen concentration of 7.3–10.2 mg/L that can be valorized if the excess water was being recycled back to the plants. Water input, excess water, and nitrogen amount were significantly different among different treatments ($P < 0.0001$).

The height of plants, number of leaves, number of tillers, and number of panicles in PIV were smaller compared to other cultivation conditions due to several limiting factors such as leaching of nitrogen content caused by the flow of excess water and slow wind velocity during the cultivation period. The latter may inhibit plant growth due to slower diffusion of gas in the plant leaf and consequently lead to a lower net photosynthetic rate as well as transpiration rate (Yabuki and Miyagawa, 1970; Monteith and Unsworth, 1990; TNAU Agritech Portal, 2016).

At the end of the cultivation period, the biomass was harvested, and the average weight of the root and stem were determined, and the results are shown in Table 4. The wet and dry weights of the biomass were not significantly different among different treatments. The average wet weight of the root lies in the range of 3.0–51.1 g whereas the average wet weight of the shoot lies in the range of 112.0–353.2 g. The average moisture content of the biomass (28.7–46.8%) was also determined, and the average dry weight is shown in Table 4. The highest average wet weight (404.3 g) was recorded when the paddy was cultivated in a screen house covered with a 50% shading net (solar irradiance of 10.3 MJ/m^2) with a water input of 1,500 mL/day and the excess water containing on average a nitrogen concentration of 5.5 mg/L was being recirculated back to the plants (PIII). A higher amount of nitrogen received by the plants because of water recirculation is reflected in the highest total amount of nitrogen content in the harvested biomass from PIII.

Table 4 Root weight, shoot weight, and nitrogen content in the paddy biomass at different cultivation conditions

Paddy biomass	Cultivation conditions				
	P0	**PI**	**PII**	**PIII**	**PIV**
Average wet weight					
Root (g)	32.7 ± 4.4	29.8 ± 0.7	26.6 ± 1.2	51.1 ± 0.4	3.0 ± 0.1
Shoot (g)	260.0 ± 30	245.4 ± 1.3	238.3 ± 21	353.2 ± 69	112.0 ± 1.1
Total (g)	292.6 ± 26	275.2 ± 0.6	264.9 ± 20	404.3 ± 69	115.0 ± 0.7
Average moisture content (%)	44.7 ± 3	54.5 ± 6	54.5 ± 3	38.9 ± 5	41.0 ± 2
Average dry weight					
Root (g)	9.3 ± 2.6	8.0 ± 0.9	4.7 ± 1.5	22.0 ± 3.9	1.0 ± 0.1
Shoot (g)	184.7 ± 36	138.3 ± 7.3	143.2 ± 15	254.1 ± 4.5	81.0 ± 2.5
Total (g)	194.0 ± 41	146.3 ± 3.8	147.9 ± 26	276.1 ± 33	82.0 ± 1.1
N content in biomass (g/100 g)	0.5	0.7	1.0	0.8	0.9
Total N content (g)	1.5	1.9	2.6	3.2	1.0

Note: P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

Effect of Production System on the Productivity of Biomass

After 114 days of cultivation, the plants were harvested, and the results are shown in Table 5. The weight of dry-harvested grains varies from 8–62 g. After shade-drying for 3 days, the reduction of moisture content varies from 11–33% and the weight of dry-milled grains varies from 5–51 g. The productivity of milled grain for each cultivation condition was estimated by dividing the dry weight of milled grain by the cultivation area (0.36 m^2). The estimated productivity of milled grain lies in the range of 0.01–0.14 kg/m^2. A very low number of harvested grains was recorded for PIV because the plants were infected by *Leptocorisa oratorius* during the cultivation period which resulted in the absence of filled grains. For other cultivation conditions, the percentage of filled grains varies from 72–83%.

According to the Indonesian Central Bureau of Statistics, the productivity of milled grain in Indonesia in 2018 is 5.9 tons/ha which is equivalent to 0.2 kg/m^2 per harvest. It is also reported that the milled grain can produce approximately 3.4 tons/ha of rice which is equivalent to 0.11 kg/m^2 per harvest. Lower productivity of milled grain was obtained in this study because no additional fertilizer was added during the cultivation period, relying only on the nutrients initially available in the cultivation media except for PIII where the leached nutrient was being recycled back to the plants. Nevertheless, the highest estimated productivity of rice was obtained for P0 and PIII (both had estimated productivity of 0.11 kg/m^2). As such highlights, the potential of the water recirculation system investigated in this study is to be further optimized and find an application on a larger scale.

Table 5 Dry weight of harvested and milled grain and percentage of filled grain at different cultivation conditions

Rice grains	Cultivation conditions				
	P0	PI	PII	PIII	PIV
Dry weight of harvested grains (g)	55.0	47.0	41.0	62.0	8.0
Dry weight of milled grains (g)	48.0	42.0	35.0	51.0	5.0
Reduction of moisture content (%)	13.0	11.0	15.0	18.0	33.0
Filled grains (%)	81.0	83.0	72.0	75.0	0
Productivity of milled grain (kg/m^2)	0.13	0.12	0.10	0.14	0.01
Productivity of rice (kg/m^2)	0.11	0.10	0.07	0.11	0

Note: P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

Effect of Production System on Water Utilization Parameters

The physiological process of the plant was strongly influenced by the amount of water available in growing media. The available water in soil was related to the ability of soil to hold water. In addition, the amount of available water is the difference between the water content under conditions of field capacity and the water content of soil (De Datta, 1933). In this study, the excess water, evapotranspiration rate (ETc), and water holding capacity (WHC) were determined regularly throughout the cultivation period and the results are shown in Figures 3A–C. Water input was determined based on the total volume of water in growing media after the saturation process for 24 hours. The volume of water input that was given to each paddy plant during the cultivation period is shown in Table 3 whereas excess water that could not be contained by the growing media due to percolation is shown in Figure 3A.

The excess water was significantly different among different treatments ($P < 0.0001$). The highest volume of excess water was obtained from PIII because the plants were watered with 1,500 mL of water. The ability of the growing media in holding water was not proportional to the total volume of water that was provided. Thus, the water passed through the growing media and leached through the soil. The average volume of excess water in PIII was 1,086 mL/day, which means that the average water holding capacity of the growing media in PIII was 414 mL. The total volume of excess water in PI, PII, and PIV was smaller than that of excess water in P0 and PIII. As such shows that input water above 1,200 mL/day resulted in excess water about 500–1,400 mL, which indicates a relatively high leaching condition. A lower water input below particularly 810 mL/day resulted in lower excess water of about 200–700 mL that corresponds to a lower leaching condition.

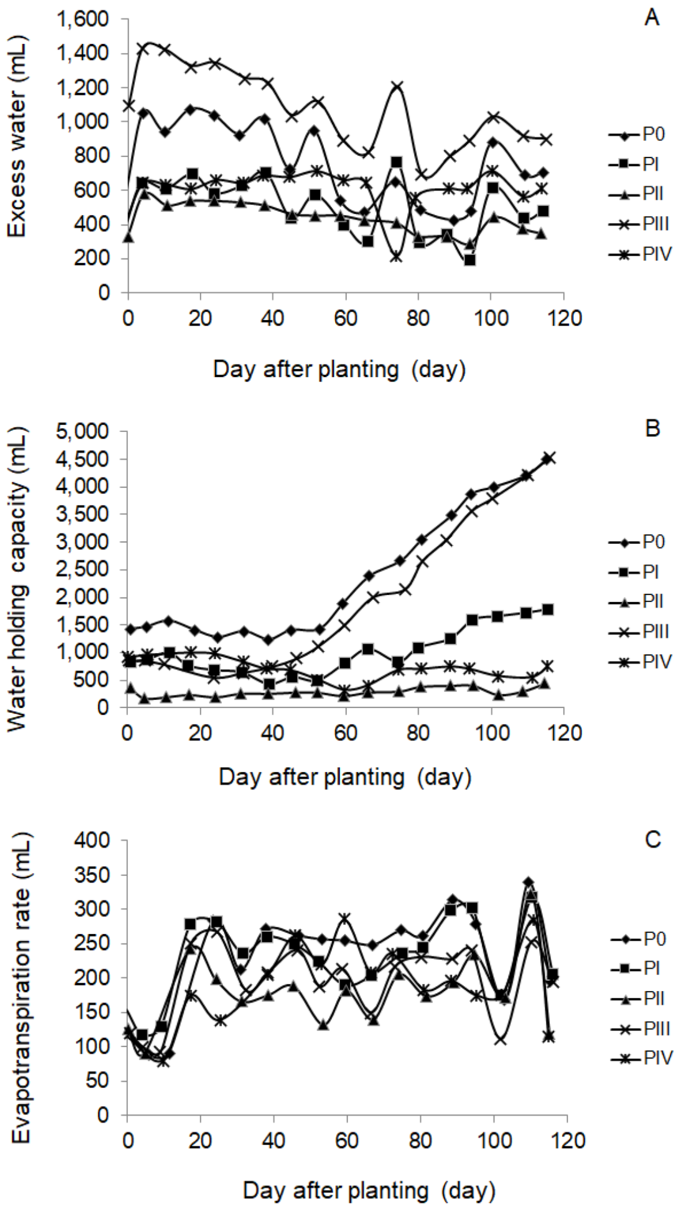

Figure 3 Excess water (A), water holding capacity (B), and evapotranspiration rate (C) at different cultivation conditions throughout the cultivation period of *Oryza sativa* L. var. Ciherang rice at Jatinangor, Sumedang. P0 = water input: 1,200 mL/day, without water recirculation, without a 50% shading net; PI = water input: 810 mL/day, without water recirculation, without a 50% shading net; PII = water input: 750 mL/day, without water recirculation, with a 50% shading net; PIII = water input: 1,500 mL/day, with water recirculation, with a 50% shading net; PIV = water input: 800 mL/day, without water recirculation, without a 50% shading net, with additional air circulation, with additional humidity

The amount of water that the growing media could hold for crop use particularly paddy as investigated in this study is shown in Figure 3B. From the figure, it can be observed that the water holding capacity of the growing media for P0 and PIII increased with time and finally reached up to approximately 4,500 mL at the end of the cultivation period. Both P0 and PIII had a water input of at least 1,200 mL/day as recommended by the FAO to increase the ability of the growing media to hold enough water for the growth of plants despite water loss due to water plant uptake, evapotranspiration, and percolation. In contrast, the water holding capacity for the growing media in PII and PIV remained stable throughout the cultivation period. As such indicates that the given water input (750–800 mL/day) is sufficient for the growing media able to maintain its level of water despite water loss during the cultivation period.

The evapotranspiration rate of the plants at different cultivation conditions throughout the cultivation period is illustrated in Figure 3C. The highest evapotranspiration rate (238 mL/day which is equivalent to 3.4 mm/day) was recorded by the plants in P0. This value is closed to the average evapotranspiration rate which lies in the range of 4–7 mm/day as reported by Tabbal *et al*. (2002). The lowest evapotranspiration rate (169 mL/day which is equivalent to 2.4 mm/day) was recorded by the plants in PII which may be contributed to the use of a 50% shade net that transmitted only 50% of the total irradiance (Chairudin *et al*., 2015).

According to Zotarelli *et al*. (2010), evapotranspiration is strongly influenced by air temperature, relative humidity, wind speed, and solar irradiance. The evapotranspiration rate is directly proportional to the solar irradiance (MJ/m^2/day). The average measured solar irradiance in P0 was 13.8 MJ/m^2/day which corresponds to an evapotranspiration rate of 3.4 mm/day. A lower solar irradiance may result in a lower evapotranspiration rate as observed for the case of PII that received the lowest solar irradiance particularly 9.1 MJ/m^2/day (Table 2) and consequently recorded a lowest evapotranspiration rate (2.4 mm/day) as well in comparison to the plants in other cultivation conditions.

CONCLUSIONS

A considerable amount of leached nitrogen was detected in the excess water that passed through the perforated containers used for the cultivation of paddy in this study. The application of a water recirculation system allows the leached nitrogen to be recycled back to the plant and promotes better physiological growth and increased the productivity of the milled grains. The application of a 50% shade net reduced the solar irradiance received by the plants and consequently decreased the evapotranspiration rate. Hence, a combination of a 50% shading net and water recirculation system may be a possible alternative for the cultivation of paddy to reduce the amount of water and nutrient input typically used in a conventional paddy cultivation system.

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