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Radiation Use Efficiency on the Different Varieties and the Number of Seedlings of Rice (*Oryza sativa* L.)

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ABSTRACT

Selection of varieties and number of seedlings per hole in rice plants is closely related to the shape of canopy, the rate of plant growth and the age of plant which determine the ability of plants to intercept and absorb solar radiation intensity. This research aimed to improve the Radiation Use Efficiency of rice by selecting plant canopies based on varieties and number of seeds per hole. Research was conducted from November 2015 to May 2016, in Landak Regency, West Kalimantan. A Split Plot Design with three replications was adopted to evaluate three varieties (Sembada-168, Inpari-30, and local varieties) as main plot, and the number of seedlings per planting hole (one, three, five, and seven seedlings per planting hole) as sub plot. Result showed that there was no interaction between varieties and the number of seedlings per hole to Radiation Use Efficiency (RUE) on rice. RUE on local variety was lower than Sembada-168 and Inpari-30. One seedling per hole had higher RUE than seven seeds with value of 3.36 and 2.17 % respectively. The number of seedlings showed that RUE of one and three seedlings per hole were higher than seven seedlings per hole.

INTRODUCTION

Rice crops are the second important food crop after wheat as it provides food for about 750 million people worldwide. About 90 % of the world's rice is consumed and produced in Asia (Zeigler & Barclay, 2008). As the major food crop, national production of rice crop for irrigated areas in Indonesia is 75.40 million tons of dry milled grain or ca. 5 t ha^{-1} in 2015 (BPS, 2016). Various efforts have been made to keep the productivity of rice crops, especially by improving the way of crops cultivation, but the increasing of temperature as result of global climate change affects the instability of rice plant productivity. Zhu, Long, & Ort (2010) reported that rice productivity in China from 1997 to 2007 tended to decline due to global climate change.

Indonesia as a tropical country provides huge sunlight ca. 12.38 MJ m^{-2} day^{-1} of solar radiation (Septiadi, Nanlohy, Souissa, & Rumlawang, 2009). The intensity of solar radiation is influenced by seasons, geographical location, and altitude. In the rainy season with many clouds, the reception of solar radiation intensity is only ca. 47 %, but in the dry season with a very bright sky without clouds, the radiation can reach 70 % (Septiadi, Nanlohy, Souissa, & Rumlawang, 2009). Suryanto, Guritno, Sugito, & Koesmaryono (2005) reported that the solar radiation intensity in Malang, East Java, ranged from 403.9 to 448.8 cal cm^{-2} $days^{-1}$ equivalent to 390.9 to 434.5 W m^{-2} with a long irradiation in one day (12 hours) between 52 % and 60 %. Related to the solar radiation intensity in the wet month i.e. from January to March, the solar radiation intensity decreases to 270.0 Cal cm^{-2} day^{-1} or ca. 261.0 W m^{-2} with 32 % of irradiation (Suryanto, Guritno, Sugito, & Koesmaryono, 2005). The increased production of rice crops is closely related to the intensity of solar radiation captured by plants and the accumulation of biomass defined as

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solar energy conversion efficiency (Slattery & Ort, 2015). The energy conversion efficiency is highly dependent on environmental factors and the ability of plants to receive the intensity of solar radiation (Slattery & Ort, 2015). The climate factors that affect the efficiency of solar energy conversion, such as latitude, season, cloud and CO_2 concentration in the plant environments, while the plant factors are the position and leaf arrangement, leaf area index (LAI) and leaf pigment type (Monteith, 1972; Monteith & Unsworth, 2013). The efficiency of light capture is also determined by the rapid development and closing of leaf canopy, size, lifetime and canopy architecture. The selection of varieties in rice plants is closely related to the shape of the canopy, the rate of plant growth and the age of the plant determines the ability of plants to intercept and absorb the intensity of solar radiation (Zhu, Long, & Ort, 2008).

The sun radiation that falls on the surface of the plant is only around 65 %, 20 % is reflected back and 15 % proceeded under the canopy. The composition of this solar radiation varies for each type of plant, depending on the type of plant in relation to the leaf area index, leaf density, head structure and wavelength of sun radiation (Vargas, Andersen, Jensen, & Jørgensen, 2002). In rice plants, variety is one of the innovations that significantly contribute in increasing production. The combination of varieties with proper seed use is expected to increase production because the number of seeds per planting hole will affect the growth due to competition among plants in one cluster. The less seedlings per hole will give space to the plant to spread and deepen rooting (Barua, Islam, Zahan, Paul, & Shamsunnaher, 2014; Islam & Salam, 2017).

Based on the important role of the solar radiation, efficiency of received solar radiation by plant can be optimized to increase the rice production. Related to the way to increase the solar radiation reception, this research aimed to improve the Radiation Use Efficiency (RUE) of rice by selecting plant canopies based on the correct varieties and the number of seedlings per hole.

MATERIALS AND METHODS

The research was conducted in Landak Regency, West Kalimantan that located at 0°10' - 1°10' North latitude and 109°5'-110°10'' East longitude. The location of the research was characterized as podsolic soil, 50 m above sea level (m asl), 160 mm month^{-1} of rainfall and 375.49-452.58 cal cm^{-2} day^{-1} solar radiation. The research was conducted from November 2015 to May 2016.

The land was prepared by plowing and harrowing using hand tractor. The 4 x 3 m plots were prepared to cultivate the 18-year-old of rice seedlings. The seedlings were planted with 25 x 25 cm spacing. Urea, SP36 and KCl as the synthetic fertilizers were applied with doses such as 400, 150, and 60 kg ha^{-1}, respectively. The Urea was applied three times i.e. at planting stage, 21, and 42 days after planting (DAP) for 20, 40 and 40 % doses respectively. The SP36 and KCl fertilizers were applied at planting stage. Leaf Area Meter (type LI – 3100) and analytic scales (type PS 1200) and oven Memmert (type 21037 FNR) were used to measure each variable for crop growth and development. Solar radiation intensity data were collected from Siantan Climatology Station, Pontianak.

The Radiation Use Efficiency (RUE) was conducted on the field. The research used a Split Plot Design (SPD) with three replications. The rice varieties and numbers of seedling per hole were the main and sub plots respectively. Sembada-168 (hybrid variety), Inpari-30 (inbreed variety), and local variety of rice (horizontal canopy) were rice varieties that selected in this research as main plot. Sub plot was the number of seedlings per planting hole i.e. one, three, five, and seven seedlings per planting hole.

The observed parameters included number of productive tillers, leaf area index (LAI), plant dry weight, percentage of filled spikelet (%), dry weight of 1000 grains (g), dry weight of grain (g plant^{-1}), yield (t ha^{-1}) and the Radiation Use Efficiency (RUE) (%). According to Yoshida (1981) and Zhu, Long, & Ort (2010), the equation of RUE was described in Equation 1. The observation was conducted at 28, 42, 56, 70 and 84 days after planting (dap) for the number of productive tillers and leaf area index (LAI).

$$RUE = \frac{\Delta W.K}{I.T.PAR} \times 100\ \% \quad \text{......................} \quad 1)$$

The Radiation Use Efficiency (RUE) was described by several components such as difference of plants dry weight (ΔW) (g m^{-2}) in a period (t), Coefficient of burning heat (K) (4,000 cal g^{-1}), Intensity of daily radiation (I) (cal m^2 day^{-1}), a period of a specific time (day) (T), and photosynthetic Active Radiation (PAR) (0.45).

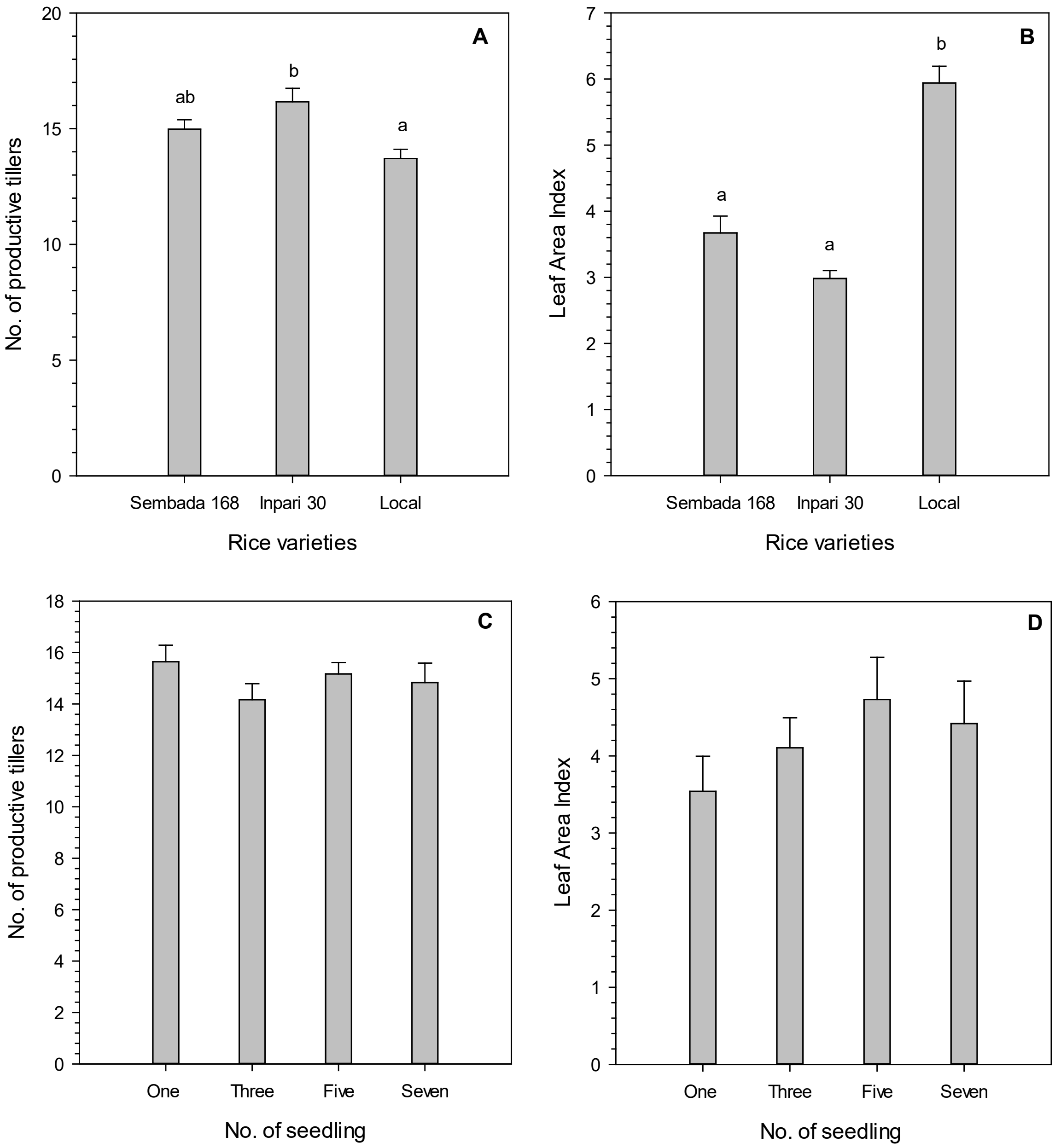

Fig. 1. Average number of productive tillers and Leaf Area Index (LAI) due to the influence of rice varieties and number of seedlings per hole; A. Number of productive tillers on three rice varieties, B. Leaf Area Index on three rice varieties, C. Number of productive tillers on four different number of seedlings, and D. LAI on four different number of seedlings. Different notations show the differences between each treatment based on LSD, α = 0.05

RESULTS AND DISCUSSION

The result showed that there was no interaction between varieties and number of seeds per planting hole on the number of productive tillers and Leaf Area Index (LAI). Rice variety of Inpari-30 had higher productive tillers compared to local variety (Fig. 1A). In contrast, local variety had higher LAI than both varieties i.e. Sembada-168 and Inpari-30 (Fig. 1B). Rice varieties influenced plant morphology. The difference of rice leaf shape has caused differences in absorption of solar radiation. The results showed that LAI of local variety was higher than Sembada-168 and Inpari-30 varieties (Fig. 1B). Rosati, Metcalf, & Lampinen (2004) stated that each species has differences on leaf sizes and canopy architecture. Photosynthetic on each leaf of various species is linearly related to daily Photosynthetic Active Radiation (PAR) incident on the leaves. The differences of species and plant growth stages can influence the light absorption. The factors affecting photosynthesis RUE (PHRUE) in plants is the leaf properties at the top canopy and daily pattern of incident light. Ahmad et al. (2009) and Khaliq, Ahmad, Hussain, & Ali (2009) stated that there is correlations between the N applying, cultivar on growth, IPAR and RUE various crops.

Inpari-30 produced higher productive tillers than the local variety, but it was not significantly different from Sembada-168. Rice varieties influence the number of productive tillers of rice plants. Inpari-30 and Sembada-168 varieties had an upright plant shape. Zhu, Long, & Ort (2010) stated that a more vertical leaf angle is the ideal plant architecture, and it causes the light to spread evenly for efficiency of light absorption. The lower leaf angle of canopy can increase carbon uptake by ca. 40 % on a shiny day.

The number of seedlings per planting hole had no effect on the number of productive tillers and LAI (Fig. 1C and 1D). However, several reports mentioned that the number of seedlings influenced tillers productivity and LAI. For examples, Hidayati, Triadiati, & Anas (2016) stated that transplanting one seedling per hill reduced competition between the plants for nutrients, water, light, and air, related to the rice growth such as plant height and tiller. In addition, Kumalasari, Sudiarso, & Suryanto (2017) stated that the Leaf Area Index (LAI) on rice plants was higher when the number of seeds planted increased.

The development of plants total dry weight showed that there was no interaction between varieties and number of seeds per planting hole. Dry weights increased from 42 to 84 DAP. From 42 to 84 DAP, Sembada-168 and Inpari-30 varieties had a higher than the local variety in total dry weight of the plants (Fig. 2A). This shows that each variety has a different response to the growing environment. According to Pratiwi & Sumarno (2014) each rice variety have a significant effect on plant height in the maximum tiller phase, plant height at harvest and plant dry weight. Among the varieties there was a diversity of resistance to pests and diseases, so that it will affect the dry weight produced. Based on the number of seedlings per planting hole, one seed per planting hole gave a high total dry weight of the plants compared to three, five and seven seedlings (Fig. 2B). The increased dry weight of plant in one seedling per plant hole was a result of the increasing of rice growth. Hidayati, Triadiati, & Anas (2016) stated that application of one seedling per hill contributes to the optimum shoot growth of rice plant.

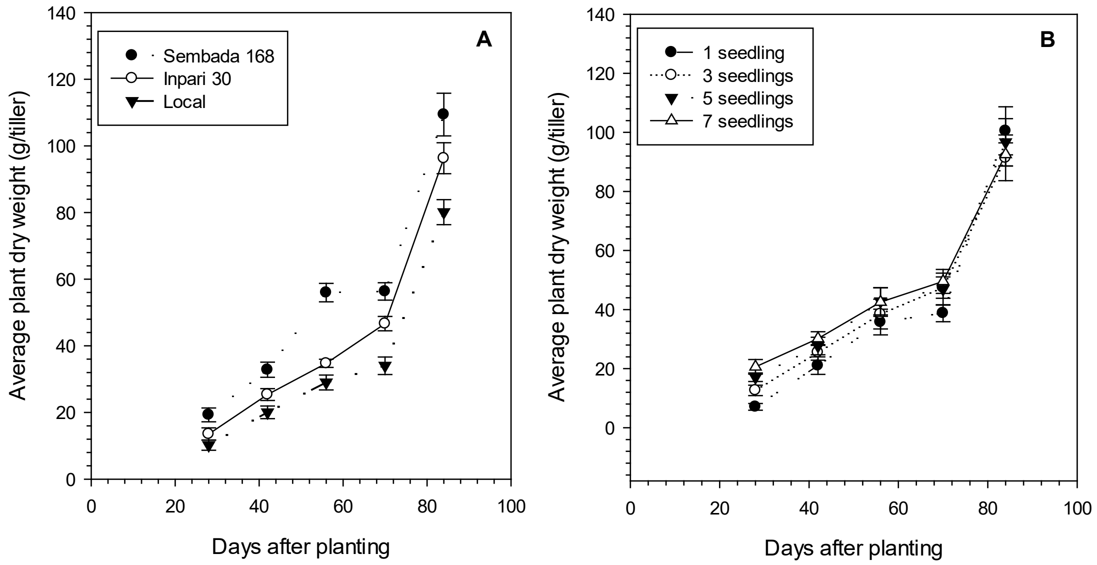

Fig. 2. Plant dry weight of rice due to (A) the effect of varieties and (B) numbers of seedling per planting hole

Table 1. Average percentage of filled spikelet (%), dry weight of 1000 grains (g), dry weight of grain (g plant^{-1}) and yield (t ha^{-1}) due to the influence of varieties and number of seedlings per hole

Treatments	Percentage of Filled Spikelet (%) (Mean ± SE)	Dry Weight of 1000 Grains (g) (Mean ± SE)	Dry Weight of Grain Per Plant (g m^{-2}) (Mean ± SE)	Yield (t ha^{-1}) (Mean ± SE)
Varieties				
- Sembada-168	87.26 ±1.42 *b*	26.47 ± 0.91	667.00 ± 54.61	6.25 ± 0.44 *a*
- Inpari-30	83.53 ± 1.57 *ab*	26.17 ± 0.88	686.92 ± 62.59	6.62 ± 0.65 *ab*
- Local	75.61 ± 2.37 *a*	26.96 ± 0.72	682.83 ± 75.16	7.50 ± 0.92 *b*
LSD 5 %	8.75	Ns	Ns	0.98
No. of seedling				
- One seedling	86.61 ± 2.20 *b*	27.03 ± 1.00	721.00 ± 86.18	7.21 ± 0.94
- Three seedlings	80.13 ± 3.28 *a*	26.21 ± 1.03	649.67 ± 82.99	6.50 ± 0.94
- Five seedlings	82.70 ± 3.15 *ab*	26.50 ± 0.97	678.11 ± 66.19	6.78 ± 0.70
- Seven seedlings	79.10 ± 0.78 *a*	26.40 ± 1.10	666.89 ± 63.25	6.67 ± 0.72
LSD 5 %	4.67	Ns	Ns	Ns

Remarks: Value in the same column followed by same letters is not significantly different (LSD 5 %)

There was no interaction between varieties treatment and number of seedlings per planting hole on number of percentage of filled spikelet, dry weight of 1000 grains, dry weight of grain per plant and yield per hectare. Separately, the treatment of varieties gave effect to parameters of percentage of filled spikelet and yield per hectare. The results showed that varieties and number of seedlings were not significantly different from dry weight of 1000 grains and dry weight of grain per plant (Table 1).

Sembada-168 variety had higher percentages of filled spikelet than local variety, but Inpari-30 was not significantly different from the local variety (Table 1). The percentage of filled spikelet is influenced by the genetics of each variety. Zaki, Gomaa, Galal, & Farrag (2009) stated that the differences in performance of filled spikelet varieties may be attributed to differences in genetically background and constitution of these varieties. Local variety produced higher yields than Sembada-168, but there was no different to Inpari-30 variety (Table 1). In this case, the local variety used a variety that had a horizontal canopy and it can absorb light and photosynthesis maximum. The yield is as much as the light interception, plants at their growth periodic use sun light and produce dry mater and save in. Satoto, Rumanti, & Widyastuti (2016) stated that the average yield production results is influenced by the environment such as light interception. According to Tohidi, Nadery, Siadat, & Lak (2012), maize hybrids had significant effect on yield in interception light and Radiation Use Efficiency (RUE).

The percentage of filled spikelet in one seedling per planting hole was higher than three and seven seedlings per planting hole, but it was not different from five seedlings per hole. One seedling per planting hole has higher yield than other varieties (Table 1). In this case, planting more than one seed in planting hole can increase the competition between plants and can affect in percentage of filled spikelet and yield. Lihiang & Lumingkewas (2017) reported that one and two seeds per planting hole provided enough space for the sunlight to penetrate the leaf. In addition, the increasing of cultivation density or the number of seedling per planting hole cause the reducing of grain number per panicle (Liu, Zhou, Li, & Xin, 2017).

The results showed that there were no interaction between varieties and plant population to Radiation Use Efficiency (RUE) on rice (Fig. 3). The Radiation Use Efficiency on local variety was lower than on Sembada-168 and Inpari-30. The number of seedlings planting hole showed that RUE of one and three seedlings per planting hole was higher than seven seedlings per planting hole, but there was no difference between one and three seedlings per planting hole. According to Murchie, Pinto, & Horton (2009), the intercepted and transmitted radiations are determined by distribution of the radiation on canopy and depend on leaf shape and canopy types. Broadly speaking, leaf position in canopy is grouped into three categories i.e. vertical or erect, horizontal or flat, and intermediate. Vertical leaves have better radiation distribution, while on horizontal leaves, most of radiation may be intercepted by the upper canopies, so that lower canopies may intercept less radiation.

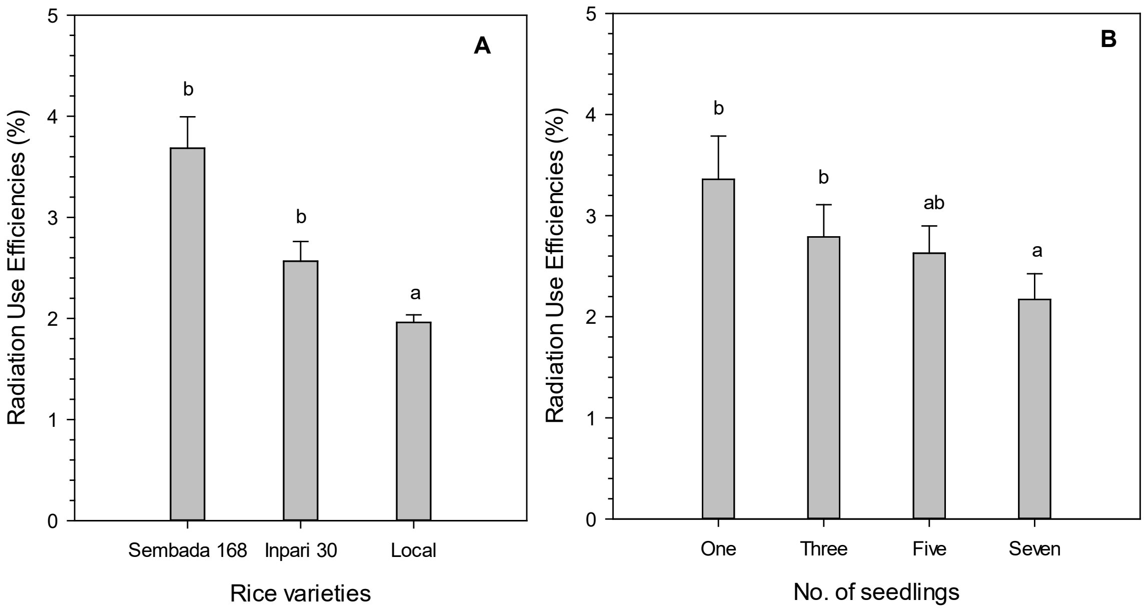

Fig. 3. Average Radiation Use Efficiency (RUE) of rice due to (A) the effect of varieties and (B) numbers of seedling per hole

Radiation Use Efficiency value of Sembada-168 variety was not different from inpari-30 variety, with value 3.68 and 2.57 % respectively (Fig. 3A). The treatment of one seed per planting hole had a higher RUE than seven seeds per planting hole with value of 3.36 and 2.17 % respectively. However, three and five seeds per hole showed the same values for RUE (Fig. 3B). According to Amthor (2010), the intercepted and transmitted radiations are determined by distribution of the radiation on canopy and depend on leaf shape and canopy types. Broadly speaking, leaf position in canopy is grouped into three categories, for instance, vertical or erect, horizontal or flat, and intermediate. Vertical leaves have better radiation distribution, while on horizontal leaves, most of radiation may be intercepted by the upper canopies, so that lower canopies may intercept less radiation. Amthor (2010) stated that RUE value for C3 is 4.6 % and C4 is 6 %. However, the maximum value of RUE for C3 before photorespiration and respiration is 12.6 %. In this case, the increasing intensity of radiation may not always increase net product of photosynthesis. But, optimal values of RUE can be achieved if the radiation intensity also increases on definite spot. On the contrary, a higher intensity may reduce RUE values. Therefore, the research results indicated different values of RUE on those three tested varieties. The result found that Sembada-168 and Inpari-30 resulted higher values than the local variety. It conformed to suggestions by Zhu, Long, & Ort (2010), that the erect (vertical) leaves are more efficient in utilizing the radiation, resulting a higher net photosynthetic product because they have more productive leaves than the horizontal type.

CONCLUSION

There was no interaction between varieties and number of seedlings per planting hole on the number of productive tillers, Leaf Area Index (LAI), and Radiation Use Efficiency (RUE) on rice. Inpari-30 and Local varieties had the highest value of productive tillers and LAI respectively. The number of seedlings per planting hole had no effect on the number of productive tillers and the LAI. RUE on local variety was lower than Sembada-168 and Inpari-30. Number of seedlings showed that RUE of one and three seedlings per hole was higher than seven seedlings per hole. The RUE value of Sembada-168 variety was not different from inpari-30 variety. One seedling per planting hole had higher RUE than seven seedlings with value of 3.36 and 2.17 % respectively. Sembada-168 and Inpari-30 varieties had a higher total plants dry weight than the local variety.

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