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Internal Versus Edge Row Comparison in Jajar Legowo 4:1 Rice Planting Pattern at Different Frequency of Fertilizer Applications

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ABSTRACT

Jajar legowo 4:1 cropping pattern has been adopted by rice farmers; however, there has been limited information on the comparison between internal and edge rows. In addition, the effects of timing and frequency of fertilizer applications on rice cultivated at riparian wetland also have to be understood. In this research, both single and split applications of fertilizer were employed. The single fertilizer applications were applied at 15 days after transplanting (DAT) (T1), 30 DAT (T2), 45 DAT (T3); and the split applications were 15+30 DAT (T4), 15+45 DAT (T5), 30+45 DAT (T6), and 15+30+45 DAT (T7). Results of this research indicated that crops in the edge rows produced higher leaf area index but those at internal rows produced higher dry weight biomass. Split fertilizer application to three times (T7) increased the weight of grains and number of filled spikelet but did not affect other shoot and root growth traits. Overall, fertilizer application increased leaf chlorophyll and nitrogen content. Jajar legowo 4:1 planting pattern and split fertilizer application to three times are recommended for increasing yield in rice cultivated at riparian wetlands.

INTRODUCTION

Rice is one of the most produced and consumed cereals worldwide since it served as the main staple food, especially in the Asia continent. The increasing of rice production and sustainable practices are important to the people who depend on rice for their livelihood. In order to meet rice demand, improving rice cultivation methods are necessary to increase its productivity and quality. Khush (2013) disclosed some strategies that could be implemented for increasing rice production.

Among various agronomic factors, planting pattern has been considered as important factor in rice cultivation. One of widely practiced planting patterns for rice cultivation in Indonesia is Jajar legowo. There are numerous types of Jajar legowo, including 4:1 planting pattern. Jajar legowo 4:1 is a rice planting pattern by creating open rows after every 4 regular rows. Rice rows on both side of every open row are recognized as the edge rows and the other two rows within each 4 regular rows are the internal rows. For compensating the open row, plant spacing within each of edge rows is half of the normal plant spacing. Adjusting plant spacing is one of the important agronomic practices for increasing crop yield and reducing plants competition with weeds and plant-to-plant competition for available water and nutrient (underground competition) and light (above ground competition).

Jajar legowo 4:1 was adopted due to convenience in crop maintenance and higher population (Erythrina & Zaini, 2014). In addition, Toyibah, Sujarwo, & Nugroho (2016) reported that jajar legowo was as an appropriate planting pattern to be applied as an effort to reduce GHG emissions, increase yield and farmer's income compare to

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conventional square or rectangle planting pattern. Kasno, Anggria, & Rostaman (2017) also used jajar legowo planting system on their study on improving rice yield by managing the sulfur application.

Paddy field in Indonesia is under tremendous pressures of conversion to other uses, such as for housing and industrial areas. Thus, riparian wetlands have been targeted area for sustaining rice production in Indonesia. The riparian wetland is locally known as ‘rawa lebak' which significantly affected by rainfall and water overflow from the nearby river. A large acreage of riparian wetlands in Indonesia is found in Sumatra, Kalimantan, and Papua. The total area of riparian wetland in Indonesia is approximately about 13.30 million ha. Since large acreage of wetland is still underutilized, it opens an opportunity to increase rice production in this sub-optimal land. At present, rice productivity at riparian wetland is still very low, approximately 1-3 t ha^{-1}. In addition to low productivity, cropping intensity is also low, due to environmental constraints. Crops usually encounter the risk of flood during the vegetative growth phase and extreme drought at reproductive stage. Thus, increasing productivity and/or cropping intensity at suboptimal lands are very challenging.

Riparian wetland in Indonesia is characterized by low soil pH and high soluble Al and Fe, as well as low nutrient availability. Sukristiyonubowo, Sipahutar, Vadari, & Sofyan (2011) categorized soil fertility at wetlands ecosystem in Indonesia as poor with a high level of iron and manganese. The high concentration of heavy metals causes the Low availability of required macronutrients and high risk of toxicity to the plants. Besides conventional approach in improving soil pH using limestone, there were more studies conducted to evaluate the effectiveness of biochar in improving soil quality (Kartika et al., in press) and rice productivity in the wetlands (Lakitan et al., 2018). Fertilizer application is necessary to enhance rice growth and increase productivity at the riparian wetland. Mahajan, Chauhan, & Gill (2011) suggested that inorganic fertilizer application was needed to provide sufficient nutrients at every growth stages. Nutrient availability is a very important for rice, not only for enhancing growth but also for improving yield.

Local farmers have practiced various timing and splitting of inorganic fertilizer application, varied from once to thrice during rice growth after transplanting. Splitting fixed amount of fertilizer could increase rice yields and minimize agrochemical pollutant leakage to open water. Cahyono & Hartati (2013) justified that split application increased the efficiency of phosphor applied to wetland rice. The excessive use of inorganic fertilizers causes low fertilizer use efficiencies and a large amount of fertilizer polluting open water and atmosphere through various means. It brought negative impact on the environment. Thus, the splitting and scheduling of fertilizer applications are beneficial for establishing economically and ecologically friendly rice cultivation practice.

Even though jajar legowo 4:1 planting pattern has been practiced by some rice farmers, there was a limited study conducted on the comparison of rice plants positioned at internal and edge rows. In addition, the effect of timing and frequency of fertilizer application on rice cultivated at riparian wetland has to be also understood in order to increase nutrient use efficiency. Therefore, the objective of this research was to compare agronomic performance of rice between internal and edge rows at varied timing of single and split applications of fixed amount of fertilizer.

MATERIALS AND METHODS

A field experiment was carried out in paddy field at riparian wetland at Pemulutan District (3°01’49”S 104°44’07”E), South Sumatra, Indonesia, from May to October 2016. The soil was analyzed prior to research at the depth of 0–20 cm. The soil contained 43.65 g kg^{-1} C-organic, 2.63 g kg^{-1} total nitrogen, 85.05 mg L^{-1} available P, and 1.84 cmol kg^{-1} exchangeable K, with a pH of 4.47. The study area was 0.33 ha of paddy field within a polder system equipped with an established water pumping system.

Rice seeds of Ciherang variety were soaked in the water for 24 hours. Ciherang is widely grown rice variety in Indonesia (Nurrahma, Junaedi, Purnamawati, & Sakagami, 2017). Pre-germinated seeds were sown at a nursery plot applying *samir* system to produce rice seedlings. *Samir* system was done by placing growing substrate mix of soil and compost at 1:1 v/v on a 70 x 100 cm woven polyethylene mats and cover with the same mats until 1 week after sowing. The seedlings then transplanted to paddy field at age of 20 days after sowing. The plant spacing followed 4:1 jajar legowo planting pattern of 50 x 25 cm at open row, 25 x 25 cm at internal rows, and 12.5 x 25 cm at edge rows. Three seedlings were transplanted in soil at a depth of ± 5 cm.

Timing and frequency of inorganic fertilizer application were: 15 DAT (T1), 30 DAT (T2), 45 DAT (T3), 15+30 DAT (T4), 15 +45 DAT (T5), 30+45 DAT (T6), and 15+30+45 DAT (T7). Each treatment has three replications and separated with 30 cm high dike. However, total fertilizer application rate was similar for all treatments at 61 kg N ha^{-1}, 15 kg P_2O_5 ha-1, 15 kg K_2O ha^{-1}, and 10 kg S ha^{-1}.The rate, type, and method of fertilizer application were adopted from current local farmer's practice. The fertilizers were evenly mixed and broadcasted to the experimental subplots according to each treatment.

The intensity of green color in leaves was measured a week after each fertilizer application using chlorophyll meter (Konica Minolta SPAD-502Plus). Based on SPAD value, chlorophyll and nitrogen contents were calculated. Crop biomass was sampled and partitioned at the end of vegetative growth stage and at harvest. Each crop organs (root, stem, leave) were separated and oven dried. Leaf length and width were measured to estimate leaf area, along with a number of leaves. The collected data used for growth analysis, included: Leaf Area Index (LAI), Shoot to Root Ratio (SRR), Root Weight Ratio (RWR), and Total Dry Biomass (TDB).

The analysis of variance (ANOVA) was performed based on the Split-plot Design with 2 main plots, 7 sub-plots, and 3 replications. For each parameter significantly affected by treatments based on results of ANOVA, the Least Significant Difference (LSD) test at $P < 0.05$ was applied for evaluating differences amongst treatment's means. Technically, collected data were analyzed using the SAS® University Edition (SAS Institute Inc., USA).

RESULTS AND DISCUSSION

Plant Growth Analysis

Leaf Area Index (LAI) was measured for comparing leaf growth and development between internal and edge rows of rice cultivated in jajar legowo planting pattern. Leaf area index (LAI) was higher on rice at the edge rows than those in the internal rows (Fig 1.A). Since edge rows had wider space, this might be due to the less competition for light interception and utilization than those at internal rows. Liu & Su (2016) reported that leaves exposed to optimum light are thicker, have a greater mass per area, a higher volume of photosynthetic machinery per unit leaf area and higher growth rates. In contrast, the light deficit in internal rows weakened photosynthesis membrane system, decreased root and blocked photosynthates transport, and then restrained leaf growth (Yang, Duan, Xie, Li, & Huang, 2011). Solar light provides energy sources for photosynthesis. The carbohydrate produced by photosynthesis breakdown to release energy for growth. The balance of photosynthesis and respiration lead to optimum LAI. These arguments were also supported by Wang et al. (2013) who found that plants at edge rows tend to have better ventilation and less competition for nutrient than those at internal rows.

Beside crop positions, timing and frequency of fertilizer application also affected LAI (Fig 1.A). Similar results obtained by the previous study on cocoyam (*Colocasia esculenta*) cultivated in degraded ultisol soil (Anikwe, Emmanuel, Eze, Ibudialo, & Edeh, 2015) and on rice in irrigated rice in China (Chen et al., 2015). Twice fertilizer applications at 15+30 DAT or 30+45 DAT showed higher LAI as compared to others timing and frequency of fertilizer applications. LAI was also found higher with 3 times fertilizer applications at 15+30+45 DAT then those crops treated with once or twice applications at equal cumulative dosage. These findings suggested that split fertilizer application increased leaf size in an attempt to maximize light interception and maximize the production of assimilates needed for growth and development. LAI increased at higher doses of nitrogen, phosphorus, and potassium applied. LAI was reported to be significantly increased with split fertilizer applications due to the more equality availability of nutrients at all plant growth stages. This might be the reason of small LAI on rice plants treated with fertilizer only at 15 DAT and 45 DAT. Nutrient availability at 30 DAT is crucial for healthy leaf growth and development in rice.

On the other hand, total dry biomass (TDB) was higher on rice plants at internal than those at edge rows (Fig 1.B). Since internal crops obtained less light than edge rows, it triggers shoot growth. This finding was in contrast with Wang et al. (2013) who found that rice at internal rows produced lower biomass than those at the edge rows. Light deficit limited photosynthesis rate and then restrained leaf growth. The effect of timing and frequency of fertilizer on TDB was similar to LAI. Split fertilizer application tended to produce higher dry biomass than those crops treated with single fertilizer application. The possibility of fertilizer loss from the rhizosphere was higher at single application since the amount of available fertilizer more than the absorbing capacity of rice roots. Split fertilizer applications reduce the potential losses. High TDBs were obtained with twice fertilizer application at T4 and T6 with an exception at T5, while the highest TDM found at 3 times split applications (T7). This indicated that the split fertilizer application was efficiently utilized by the plant, thus making it possible for the plant to translocate the carbohydrates into the organs.

Shoot to root ratio (SRR) of rice was relatively similar both at the edge and internal rows if fertilizers split for 3 or 2 applications during the vegetative stage. It was due to jajar legowo planting pattern makes all plants into plants aside to absorb sunlight and good air circulation. Interestingly, single fertilizer application at early vegetative stage increased SRR on rice at the edge rows (Fig 2.A). Yet, late fertilizer application increased SRR on rice at the internal rows. According to Hayat, Ahmad, & Alyemeni (2013), the decreasing in light irradiance (a sum of total light that plant could absorb) caused an increase in shoot elongation. Shoot growth could be leaves and stems, but in this study, LAI of plants at internal rows was lower than those at edge rows. It showed that shoot growth as affected by low light mainly occurred in the stem of rice. The effect of fertilizer application on SRR was supported by higher root weight ratio (Fig 2.B). It appeared that a smaller value of shoot to root ratio was mainly as a result of higher root weight rather than lower shoot weight.

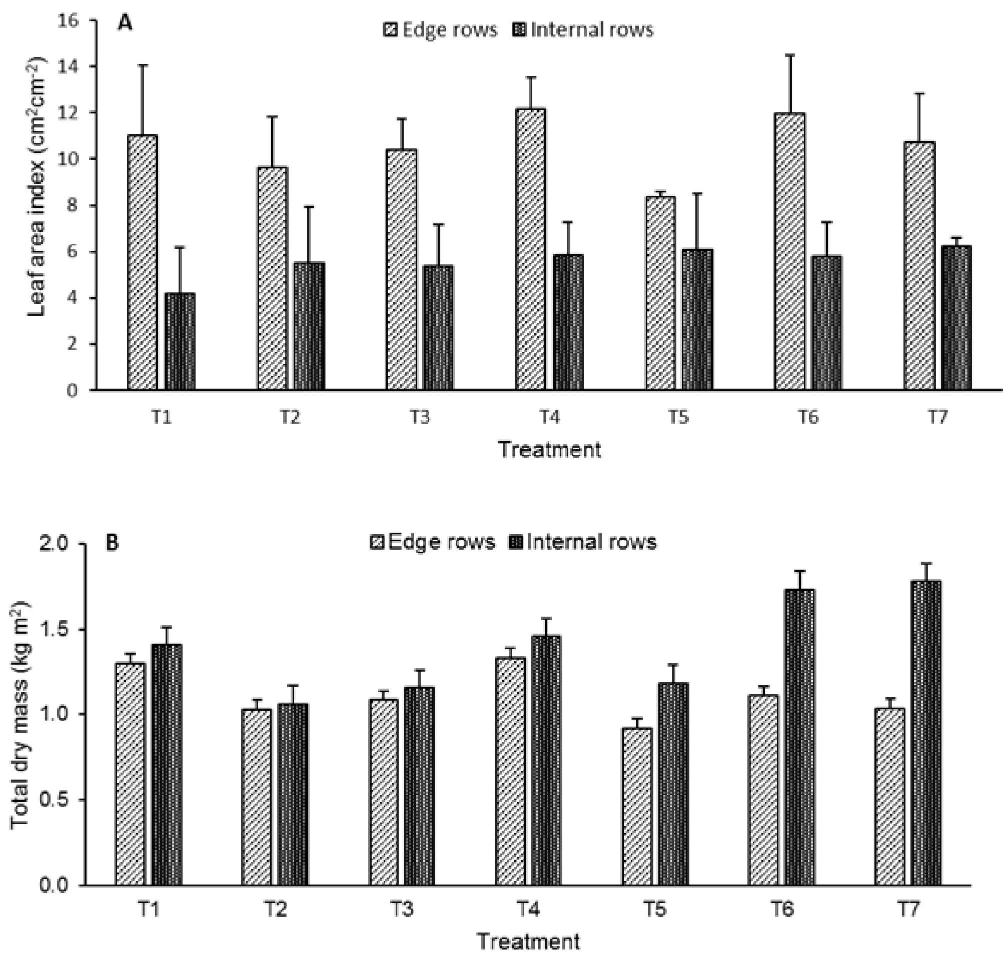

Fig. 1. Contrary effect of different frequency of fertilizer application on leaf area index (A) and total dry mass (B) on rice in internal and edge rows 4:1 planting system.

Both shoot and root increases were associated with late fertilizer applications of 30 DAT, 45 DAT, and other treatments combined with both or either of these late applications. It assumed that existing nutrients at riparian wetland are sufficient for the early vegetative stage of rice. The study of Yoseftabar (2012) revealed that young rice before the tillering stage grew slowly and did not need much fertilizer therefore only a small to moderate amount of fertilizer needed. However, at later growth stages, a higher amount of nutrients was required for rice growth and development. Therefore, split fertilizer application was better in matching supply and demand of nutrients by the plants. Split fertilizer application increased nutrient use efficiency (Sitthaphanit, Limpinuntana, Toomsan, Panchaban, & Bell, 2010).

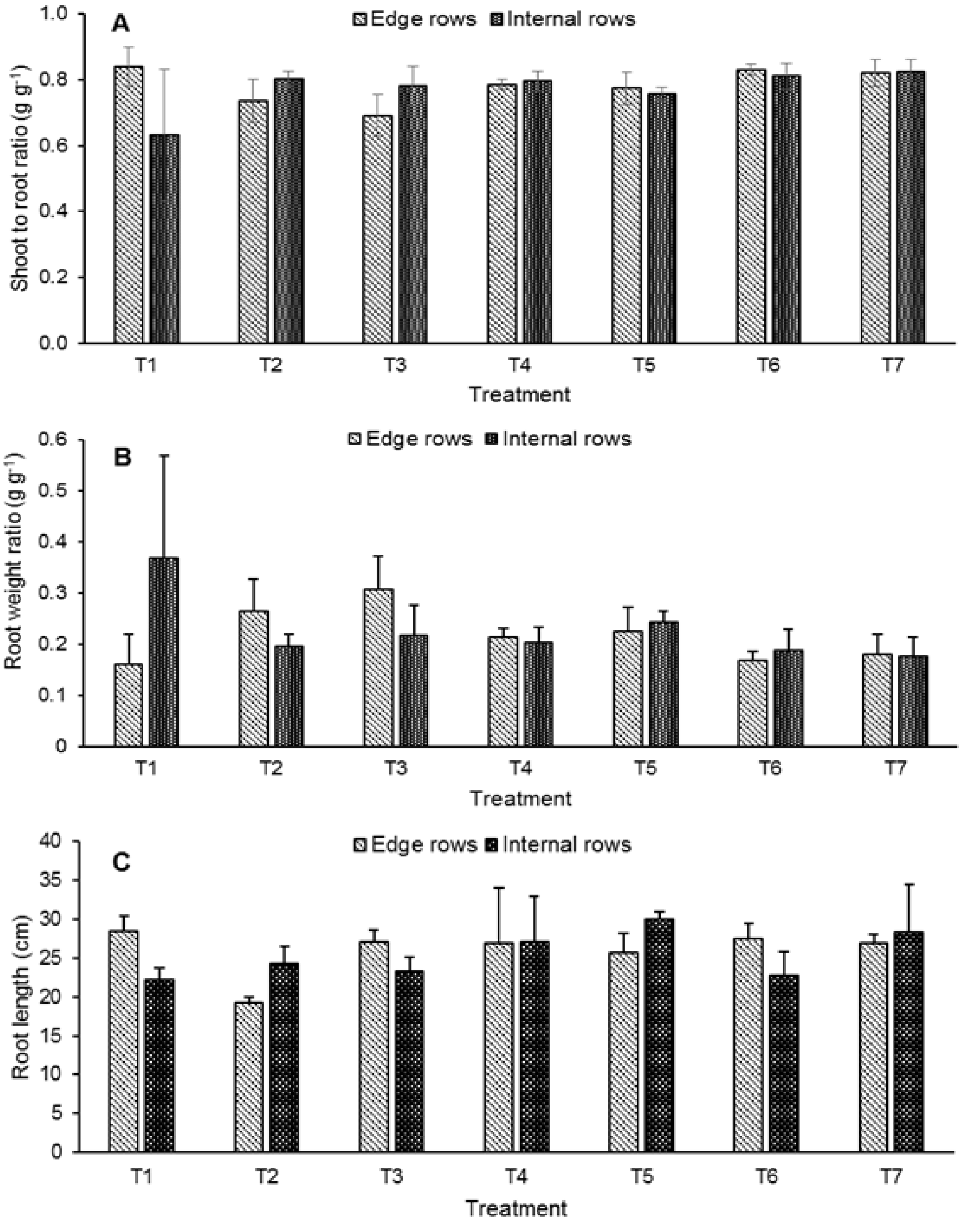

Fig. 2. Effect of different frequency of fertilizer application on shoot to root ratio (A), root weight ratio (B), and root length (C) on rice in internal and edge rows 4:1 planting system.

Root length was measured to observe the effect of crop position, timing, and frequency of fertilizer application on the underground competition. However, in this study, root length was not directly associated with crop position; it was varied with different timing and frequency of fertilizer application (Fig 2.C). The wider spacing of tillers would probably improve the root growth both vertically and horizontally as compared with a narrower spacing narrower. In this study, RWR was not affected by root length. It was found that the higher RWR was in contrast with root length. According to Carmeis Filho, Crusciol, Nascente, Mauad, & Garcia (2017), the root length density was a genetically controlled character and caused the differences among cultivars. Root length increased at a higher frequency of fertilizer application, especially for plants at internal rows.

SPAD Value, Chlorophyll Content, and Nitrogen Content

SPAD value on rice plants at both edge and internal rows were not significantly different at all scheduled observations (Fig 3.A). Meanwhile, the frequency of fertilizer application strongly affected SPAD value as indicated by the trend of SPAD values at a week after each fertilizer application (Fig 3.B). SPAD value was higher on fertilized crops than unfertilized crops. It suggested that nutrients were absorbed by crop and utilized to increase leaf chlorophyll content and nitrogen content. A similar result was reported by Yoseftabar (2012) that split fertilizer applications significantly affected SPAD values. This study revealed that the SPAD value was increased significantly in rice plants treated with split fertilizer applications. Nitrogen application can be applied three or four times at different growth stage based on crop needs and growing conditions.

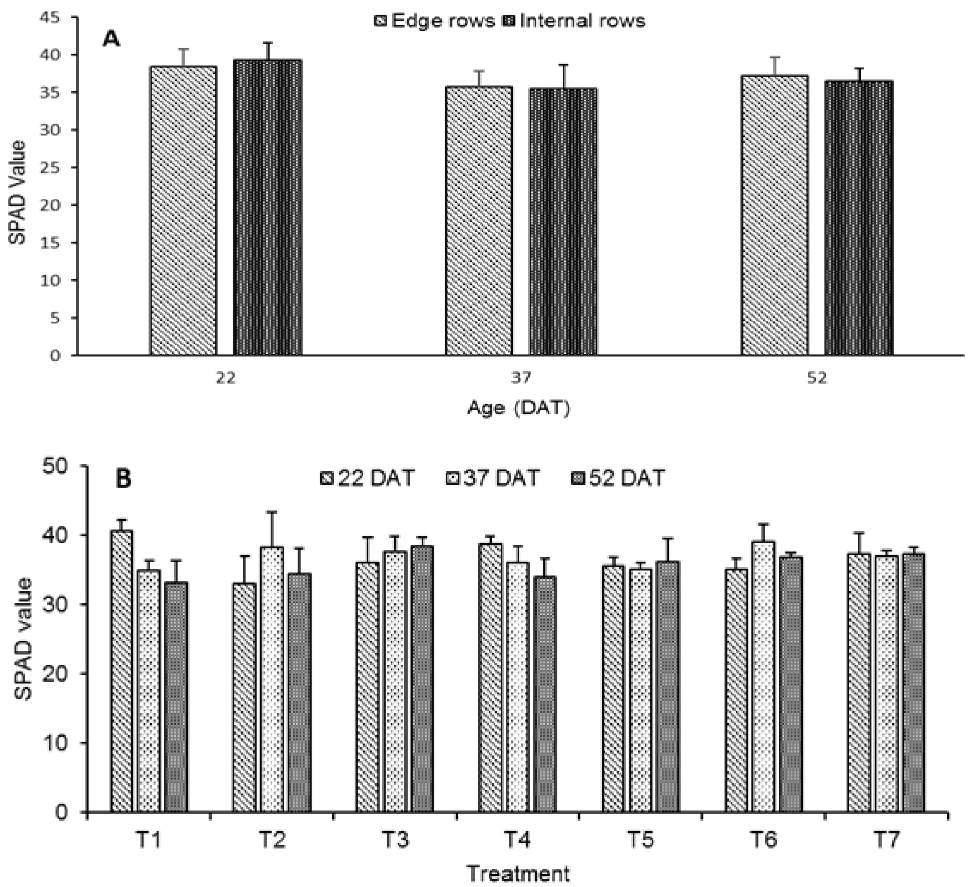

Fig. 3. SPAD value on rice in internal and edge rows in 4:1 planting system (A) and on crops treated with different time and frequency of fertilizer application (B)

SPAD value was measured to estimate leaf chlorophyll contents and N-kjeldahl contents (Table 1). Swain & Jagtap Sandip (2010) reported that chlorophyll meter provides instantaneous and nondestructive information on crop N status. In addition, Hassan, Khair, Haque, Azad, & Hamid (2009) stated that SPAD reading indicated the plant nitrogen status which could be used as a reference for application of nitrogen fertilizer to satisfy nitrogen requirement of the crop at different growth stages. In this study, split application of fertilizer increased SPAD value as well as N content at all growth stage.

Table 1. Chlorophyll and nitrogen content during vegetative stage of rice treated by different frequency of fertilizer application.

Timing of fertilizer application	Sampling Day		
	22 DAT	37 DAT	52 WAT
	Chlorophyll content (mg g^{-1} FW)		
T1	2.220±0.113*	1.823±0.104	1.697±0.221
T2	1.687±0.282	2.057±0.351	1.794±0.254
T3	1.901±0.250	2.009±0.157	2.061±0.091
T4	2.087±0.081	1.898±0.165	1.754±0.0.191
T5	1.865±0.086	1.830±0.069	1.912±0.227
T6	1.835±0.110	2.105±0.176	1.958±0.041
T7	1.991±0.207	1.970±0.054	1.992±0.067
	N-kjeldahl (mg g^{-1})		
T1	68.490±2.570	59.424±2.372	56.550±5.040
T2	56.315±6.432	64.757±8.010	58.766±5.788
T3	61.200±5.710	63.657±3.582	64.851±2.082
T4	65.450±1.848	61.141±3.757	57.843±4.357
T5	60.377±1.953	59.583±1.575	61.459±5.179
T6	59.695±2.499	65.862±4.011	62.499±0.934
T7	63.252±4.727	62.781±1.221	63.275±1.538

Remarks: * = Mean ± standard deviation

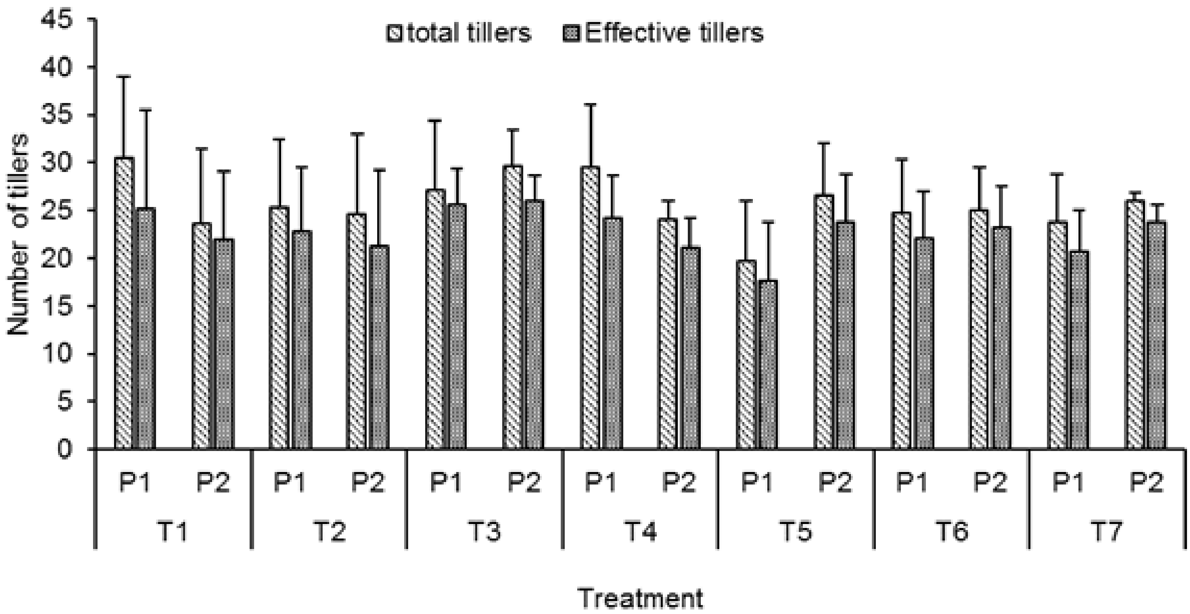

Fig. 4. Effect of crop positions and frequency of fertilizer application on number of total and effective tillers.

Table 2. The effect of timing and frequency of fertilizer application and crop positions on yield components.

Treatment	Panicle length (cm)	Grains per panicle (g)	Filled Spikelets/Panicle (%)	Sterile spikelets/panicle (%)
		Timing and splitting of fertilizer application		
T1	26.9	3.97 b*	85.73 b	14.27 b
T2	26.1	3.96 b	86.51 b	13.49 b
T3	23.49	3.79 b	84.22 b	15.78 b
T4	26.22	4.44 a	90.54 a	9.46 a
T5	25.72	3.69 b	85.87 b	14.13 b
T6	25.48	4.46 a	90.74 a	9.26 a
T7	26.74	4.63 a	89.44 a	10.56 b
LSD (0.05)		0.45	6.57	6.07
		Crop position		
P1	25.81	4.02	86.85	13.15
P2	25.79	4.25	88.31	11.69

Remarks: * = Mean values within a column followed by the same letters are not significantly different at $p < 0.05$

The increment of SPAD value in this study was also affected by the addition of potassium. According to Fanaei, Galavi, Kafi, & Bonjar (2009), increase in leaf SPAD values due to the addition of potassium was associated with the increase of nitrate reductase enzyme activity. SPAD value is important to estimate chlorophyll and N-kjeldahl contents. However, successful use of SPAD for estimate chlorophyll contents may be affected by many external factors (Huang et al., 2008; Monostori et al., 2016; Xiong et al., 2015).

Effective Tiller and Other Yield Components

Grain yield of rice is highly dependent upon the number of effective tillers per produced by each plant. However, in this study, the effect of plant position on the number of tillers and productive tillers were not consistent (Fig. 4). The higher number of total and effective tillers at the edge rows showed at T1 and T4. The lowest of total and effective tillers at internal rows was obtained by T3 and T5. Meanwhile, T2, T6, and T7 showed similar number at the edge and the internal rows. Results showed that number of tillers was more affected by fertilizer application frequency. The number of tillers in rice mainly affected by variety, time of transplanting, planting system, water supply and fertilizer application (Tian et al., 2017). In this study, split fertilizer applications at early vegetative stage increased number of tillers since the applications were within the tiller development phase. Productive tillers per hill can be used as a reliable trait for predicting rice yield.

Increasing grain yield is the most important subject of rice cultivation in a riparian wetland. Grain yield is a result of interactions among various yield components (Fageria & Santos, 2015). Results indicated that there was no significant effect of crop positions on yield components, including panicle length, grains per panicle, filled spikelet and sterile spikelet. Whereas fertilizer application was significantly affected the weight of grains per panicle, the percentage of filled spikelet and sterile spikelet (Table 2). Panicle length and grains per panicle variables are important for resulting higher yield. Split fertilizer application at 15+30+45 DAT produced a higher number of grains per panicle as compared to other treatments. The number of panicles is correlated with the number of tillers per hill developed during the vegetative stage. Therefore, an appropriate amount of fertilizer application would trigger tillering phase and result in a higher yield. Rusdiansyah & Saleh (2017) reported that single nitrogen application also affected tillers per hill and other yield components in local rice varieties in Indonesia.

The increase in nutrients uptake leading rises the percentage of filled spikelet, weight of grains per panicle, and at the end produces higher yield (Prasad, Sajjan, Vyakaranahal, Nadaf, & Hosamani, 2008). Filled spikelet per panicle was the most important yield component in which was affected rice yield. The crops fertilized with two and three times of applications showed the higher percentage of filled spikelet. Once and twice fertilizer applications lead to insufficient nutrients during grain filling process and reduce grain numbers per panicle (Wei et al., 2011). Grain filling was rested on assimilates supplied from photosynthetic activity (Yoseftabar, 2013). Some experienced farmers usually save a portion of fertilizer to be applied late at panicle initiation stage for increasing percentage of the filled spikelet.

There was no significant difference in panicles length between single and split fertilizer application treatments. However, T1 fertilized at 15 DAT and T7 fertilized at 15+30+45 DAT resulted in longer panicle than the other treatments did (Table 2). The weight of grains per panicle was associated with filled spikelet. In rice, many factors affect the number of spikelets per panicle, such as genotype, cultural practices and growing conditions (Yoseftabar, 2012). Nutrients management is important in improving the balance between crop nutrients demand and nutrients supply from soil and applied fertilizer to produce high grain yield.

In this study, split fertilizer application showed a higher effect on rice growth at riparian wetland ecosystem. Meanwhile, in most cases, availability of macronutrients at riparian wetland is insufficient for supporting optimal rice growth. Rice cultivation, particularly in riparian wetland ecosystem, requires careful nutrient management. Nitrogen, phosphorus, and potassium are three most important elements and have to be available during crop growth. Split fertilizer application would also improve their availability and enhance both rice vegetative growth and yield. Fertilizer application at early vegetative stage increases the risk of nutrient loss from the root zone, whereas fertilizer application during the period of rapid nutrient uptake at late vegetative and early reproductive stages can reduce the loss of applied fertilizer due to its rapid uptake by plants. Nitrogen demand during rice growth can be predicted based on leaf characteristics (Ata-Ul-Karim et al., 2017) or leaf chlorophyll content (Saberioon et al., 2014; Yuan et al., 2016).

CONCLUSION

Rice plants at the edge rows in jajar legowo 4:1 planting pattern resulted in higher leaf area index but the plants in internal rows produced higher total dry mass. Fertilizer application three times during vegetative growth increased grain weight per panicle, the number of filled spikelet, chlorophyll and nitrogen contents. In order to improve rice growth and yield, jajar legowo 4:1 planting pattern and fertilizer application three times at 15, 30, and 45 DAT are recommended.

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