Pertanika J. Trop. Agric. Sci. 41 (2): 637 – 654 (2018)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Rice Ratooning Using the *Salibu* System and the System of Rice Intensification Method Influenced by Physiological Traits

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ABSTRACT

Rice productivity can be increased by improving land productivity with a ratoon crop of *salibu* system cultivated with the System of Rice Intensification (SRI) method. Rice cultivation using SRI is a method to increase the rice growth and development by managing the plants, soil, water and nutrients. Ratooning is the ability of the rice plant to regenerate new tillers after harvest. The beneficial aspects of ratoon are the increase of rice productivity and efficiency in terms of time, labour and cost. The local people of West Sumatra commonly re-cut the rice stalk at seven days after the main crop harvest. This method is called the *salibu* system, which is a modification of a ratooned crop that produces a higher yield than the non-*salibu* system (no cutting after first harvesting). The aims of this study are to analyse the physiological characteristics of ratooned rice and its agronomic performance under the *salibu* system using the SRI method. The Randomised Complete Block Design (RCBD) was used for the main crop to compare SRI and conventional methods, while RCBD with the factors of cutting technique and cultivation methods was used for the ratooned crop. The cultivation methods were SRI and the conventional methods, while the cutting technique was the *salibu* vs the usual (non-*salibu*) systems. The results indicate that the main crop under SRI was found to have a greater photosynthetic rate and higher vegetative and reproductive parameters than plants cultivated under the conventional method. The above trends were also observed in the ratooned crop for SRI using the *salibu* sytem compared with other combinations of

ARTICLE INFO

Article history:
Received: 22 June 2016
Accepted: 26 January 2018

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ISSN: 1511-3701

cutting and cultivation methods. There was no interaction between cutting technique and cultivation method in the ratooned crop. The main crop yield using SRI was 24% higher than using the conventional method. Subsequently, the ratoon-crop yield under the *salibu* system using SRI was approximately 50% of the main crop. The ability of rice plants to produce a ratoon crop was highly influenced by their carbohydrate content and the phytohormones that remain in the intercalary meristem tissues of stubble after harvest. Furtheremore, better yield of the ratooned crop is possible by increasing fertilisers (especially nitrogen), as could be done in future research into ways of improving this innovation.

Keywords: Carbohydrates, intercalary meristem, photosynthetic, phytohormones

INTRODUCTION

An innovative cultivation technology for irrigated rice, namely, the System of Rice Intensification (SRI) developed in Madagascar, has been found to be capable of substantially improving rice productivity (Kabir & Uphoff, 2007; Sato & Uphoff, 2007; Thakur et al., 2010; Wu et al., 2015). However, SRI is still a developing innovation whose concepts and practices have been proven in increasing rice output and farmers' income but decreasing input such as seeds, fertilisers, pesticides and water. The increase of yield is achieved not by introducing new varieties or increasing external input, but rather by changing the management of plants, soil, water and nutrients (Ahmed et al., 2015; Barison & Uphoff, 2011). SRI proposes the use of young sedlings (8-12 days), planting of single seedlings (just one seedling per hill), wider spacing (usually 25 cm x 25 cm), maintaining moist soil condition (without flooding), use of a mechanical weeder that also aerates the soil, thus providing optimal growth conditions for the plants and enhanced soil organic matter. These practices aim to obtain better performance in terms of yield and resource productivity (Stoop et al., 2002). In contrast to SRI practices, the conventional method generally involves using considerably older seedlings (25 days old or more), planting three to five seedlings per hill, using closer spacing (20 cm × 20 cm or less), maintaining soil condition i.e. mostly flooded and fertilisation mostly using inorganic fertiliaers (Kediyal & Dimri, 2009). The effectiveness of the SRI method has been demonstrated in more than 50 countries around the world, including major rice-producing countries such as India, China, Vietnam and the Philippines (Katambara et al., 2013). The suitability of using SRI in Indonesia has been reported in various studies, showing SRI practices increasing rice yield by 24-78% (Bakrie et al., 2010; Hidayati et al., 2016; Hutabarat, 2011; Sato & Uphoff, 2007).

In addition to using the SRI method, growing a second rice crop from harvested plants (a practice known as ratooning) is the newest practical way to increase total rice production per unit area. A ratoon is a new stalk with regrowth of new tillers after the main crop is harvested using a sickle knife.

Ratoons can increase rice productivity by the second cropping season at a low additional cost. Ratooning is a practical method to increase the additional number of rice panicles per unit of area and of time, provided that the plants can produce new tillers and branches at the base and nodes of the harvested plant of the main crop (Akhgari & Niyaki, 2014; Harrell et al., 2009; Nair & Rosamma, 2002; Oad et al., 2002a) .

Ratoon rice has a shorter production period than that of the main crop (Akhgari & Niyaki, 2014; Chauhan et al., 1985; Faruq et al., 2014; Oad et al., 2002b). Production costs are lower due to the minimal expenditure needed for land preparation, transplantation, and crop maintenance (Faruq et al., 2014). Although a ratooned rice crop can be harvested in 45 days after harvesting the main crop, its production is generally and relatively low compared with its main crop using the conventional method i.e. one ton per ha (Suwandi et al., 2012). In a field trial in Bangladesh, Begum et al. (2002) showed that the highest grain yield (1.56 t ha^{-1}) resulting from a ratoon crop was 25.2% of the main crop. The yield and most of the other plant attributes were lower and its field duration was also shorter than that of the main crop.

Uneven growth and maturation of plants, various diseases and insect attack are the main causes for production of ratooned rice than the main crop (Chauhan et al., 1985; Oad et al., 2002a, 2002b). However, the production of ratooned rice can be improved with harvesting technology. Erdiman (2013) reported that local people in West Sumatra, Indonesia, commonly re-cut the rice stalk at seven days after main crop harvesting. This method is called the *salibu* system, which is a modification of the ratoon crop, and it eventually allows higher production than the usual (non-*salibu*) methods (no cutting of the rice stalk after main-crop harvesting). Getting a second rice crop from the same planting benefits farmers due to the shorter cycle for the second crop and cheaper production costs as a result of no tilling and raising seedlings (Faruq et al., 2014; Nair & Rosamma, 2002; Sanni et al., 2009; Tari, 2011). A second rice crop under the *salibu* system has higher production than that using standard methods; however, the reasons for this, traceable to particular physiological characteristics of ratooned rice plants using the *salibu* system, are still not widely known. Therefore, this study was carried out with the aim of analysing and evaluating the physiological characteristics of ratooned rice under the *salibu* system when using the SRI method, especially under Bogor's rice-growing conditions.

MATERIALS AND METHOD

Research Site

This study was conducted from June 2014 to February 2015 in Sindang Barang Jero, West Bogor District, Bogor. The materials used in this study were Ciherang rice variety and inorganic fertilisers i.e. urea (45.7% N), SP-36 (36.3% P_2O_5), KCl (61.1% K_2O) and 2.5 t compost per ha.

Experimental and Treatment Design

The Randomised Complete Block Design (RCBD) was used to assess the SRI and conventional methods used for raising the main crop, while RCBD with the factors of cutting technique and *cultivation methods* with five replications were used for the ratooned crop. The first factor evaluated was cutting technique, with two treatments i.e. the *salibu* and non-*salibu* harvesting systems (Figure 1). The second factor was cultivation method, which compared two treatments i.e. the SRI and conventional agronomic methods. There were 20 experimental units (2 m x 2.5 m for each unit).

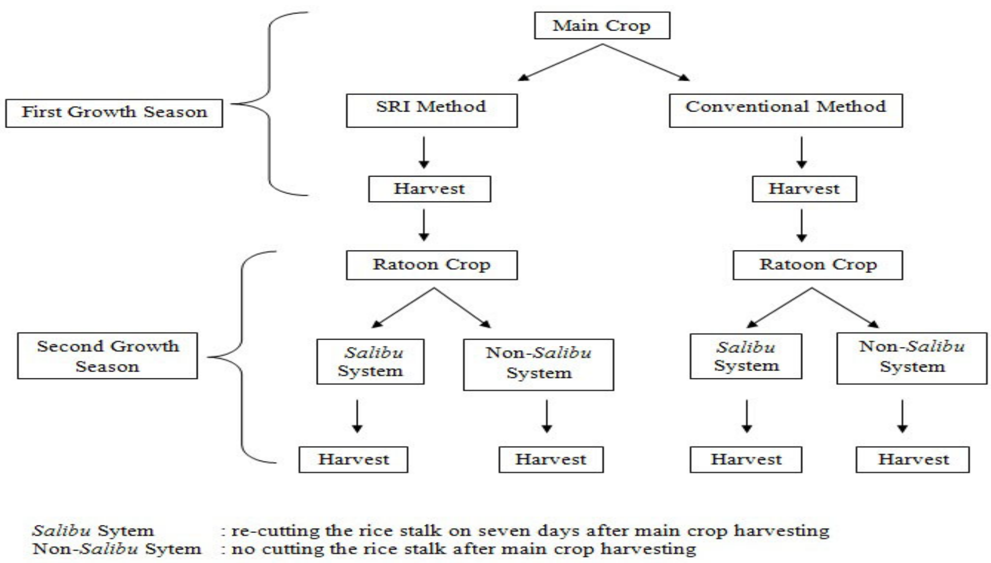

Figure 1. Research schemes

Cultivation System

Main crop. Seedlings were prepared by soaking the seeds in warm water for 24 h, then air-drained and incubated for two days until germination. In the SRI method, the seedlings were planted in a tray, with soil and organic fertilisers, and grown for 10 days. In the conventional method, seeds that had been incubated for two days and germinated were sown in a standard nursery for 25 days before transplanting using the usual practice. Using the SRI method, the seedlings were transplanted one seedling per hill with spacing 25 cm x 25 cm. In the conventional method, the seedlings, spaced 20 cm x 20 cm, were transplanted five seedlings per hill. The SRI plots were weeded by conoweeder at 10, 20 and 30 days after transplanting, while the conventional plots had two hand weedings at 10 and 20 days after transplanting.

With respect to nutrient provision, both SRI and conventional treatments used the same type, dose, timing and application of fertilisers, so soil nutrient amendments were not a variable in this trial. In this experiment, inorganic (125 kg urea per ha, 100 kg SP-36 per ha and 50 kg KCl per ha, which was equivalent to 250 g urea per plot, 200 g SP-36 per plot and 100 g KCl per plot) and organic (2.5 t per ha, equivalent to 5 kg per plot) fertilisers were used i.e with the proportions of 50% inorganic and 50% organic from the total applied fertilisers. The organic fertilisers was compost that was applied at transplanting together with SP-36 and KCl fertilisers, while urea was applied twice, half dosage was applied during transplanting and the remaining at 42 days after sowing (DAS). In the SRI method, to keep the soil moist, a trench along the inner edge of the plot (size 20 cm x 20 cm x 30 cm) was flooded with water. Shortly before weeding, the plots were flooded to a water level of about 2 cm, while the soil medium in the conventional plots was kept continuously flooded at 5 cm of standing water until grain ripening. Insecticide was used only if symptoms of a pest attack appeared. In both cultivation methods, water was drained five days before harvest. Harvest of the SRI and conventional plots was carried out when 80% of the rice grains turned yellow. The main crop was harvested by using a sickle knife by cutting the stalks at 20 cm from above the ground.

Ratoon crop. ***Non-salibu system.*** Harvesting of the main crop was carried out at 105 DAS by cutting the stalks of the rice plants at 20 cm above the ground. The soil was then kept continuously flooded at 5-cm height of water for three days prior to re-drainage. Irrigation water, such as applied for the main crop, was provided after all the new shoots had already emerged. Five days after harvesting the main crop (5DAH), only inorganic fertiliser was applied (125 kg urea per ha, 100 kg SP-36 per ha and 50 kg KCl per ha, which was equivalent to 250 g urea per plot, 200 g SP-36 per plot and 100 g KCl per plot). Harvesting was carried out when 80% of the rice grains had turned yellow (Erdiman, 2013).

Salibu system. After the harvesting of the main crop, the soil medium was kept continuously flooded at 5 cm height of water for three days prior to re-drainage. Four days later, the remaining stalks were re-cut to only 5 cm above the ground. Irrigation water, such as applied for the main crop, was provided after all the new shoots emerged. Weeding, replanting and thinning were carried out 10 days after cutting. In this experiment, only inorganic fertiliser was used at the amount similar to that applied in the non-system. SP 36 and KCl were applied at 10 days after cutting the main crop, whereas the urea was applied at 10 and 30 days after cutting. Harvesting was carried out when 80% of the rice grains had turned yellow (Erdiman, 2013).

Vegetative and Reproductive Growth Parameters

The vegetative growth parameters measured for main and ratoon crops were tiller number, leaf number, shoot dry weight and root dry weight at 105 days after sowing (DAS) for the main crop and at 75 days after the harvest of the main crop (DAH) for the ratoon crop. The number of productive tillers per hill and the number of productive tillers per m^2 were determined for both crops. In addition, the reproductive parameters observed were weight of 1000 grains, grain dry weight per hill, grain dry weight at harvested per m^2 and grain yield dry weight per m^2 (yield after drying under the sun).

Physiological Parameters

Net photosynthetic rate measurements. From each plot, the flag leaves during the peak vegetative and reproductive stages of the main and ratoon crops were marked for measuring the photosynthetic rate using Licor 6400XT (Nebraska, USA) at PAR of 2000 µmol photons m^{-2} s^{-1}.

Internal carbohydrate measurements. Internal carbohydrates in the stubbles' intercalary meristem tissue were measured using the phenol-sulfuric acid method (Dubois et al., 1956) during the harvesting of the main crops using the non-*salibu* system and seven days after using the *salibu* system.

Phytohormones analysis. Gibberellins, cytokinins and auxins in the stubbles' intercalary meristem tissue were measured using the method of Unyayar et al. (1996) during harvesting of the main crops in the non-*salibu* system and seven days after using the *salibu* system.

Data Analysis

All the data relating to the main crops were statistically analysed using the independent t-test with α=5% level of probability, while the ratoon crop data were analysed using the analysis of variance (ANOVA) method. Mean comparisons were carried out using Duncan's Multiple Range Test (DMRT) at p=5% level.

RESULTS

Vegetative Growth

In the main crop, the number of tillers per hill and the number of leaves were higher in plants raised using the SRI method than the conventional method. The number of tillers at 38, 53 and 68 DAS using SRI were 13.3, 31.1 and 37, respectively, while the number of tillers under conventional management were 8.4, 22.5 and 24.9, respectively (Figure 2a). The number of leaves at 38, 53 and 68 DAS under SRI were 40.1, 105.8 and 149.8, respectively, while the number of leaves under conventional management were 26.9, 80.7 and 108.8, respectively (Figure 2b). The SRI method also produced higher shoot and root dry weights at 105 DAS, higher by 34.3% and 82.5%, respectively. The number of productive tillers per hill was higher using the SRI than the conventional method i.e. 24.9 and 14.6, respectively. The SRI method could increase the number of productive tillers per hill by 71.1%. However, on an area basis, the number of productive tillers per m^2 under both methods showed a difference that was not significant (Table 1). It was due to a lower hill number, which related to wider plant spacing.

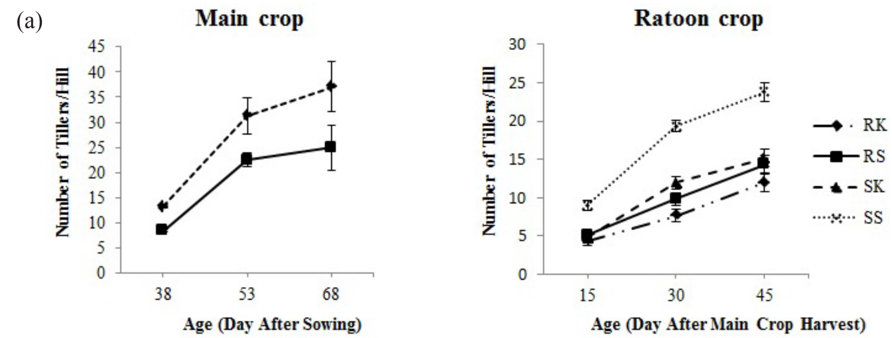

Figure 2(a) : Number of tillers per hill of main crop (....: System of Rice Intensification; — : conventional) and ratoon crop (RK: conventional non-*salibu*; RS: SRI non-*salibu*; SK: conventional *salibu*; SS: SRI *salibu*). Bar line on the graph shows the standard error

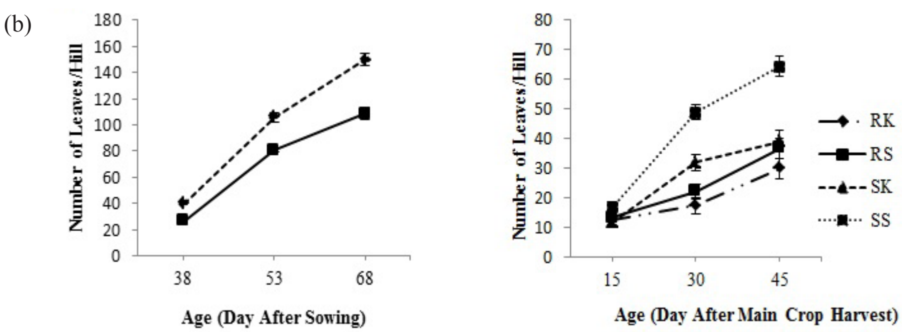

Figure 2(b) : Number of leaves per hill of main crop (....: System of Rice Intensification; — : conventional) and ratoon crop (RK: conventional non-*salibu*, RS: SRI non-*salibu*; SK: conventional *salibu*; SS: SRI *salibu*). Bar line on the graph shows the standard error

Table 1
Number of productive tillers per hill, number of productive tillers per m^2, shoot dry weight per hill (g hill^{-1}) and root dry weight per hill (g hill^{-1}) of main and ratoon crops

Treatment	Number of Productive Tillers per Hill	Number of Productive Tillers per m^2	Shoot Dry Weight per Hill (g hill^{-1})	Root Dry Weight per Hill (g hill^{-1})
- - - Main crop - - -				
SRI	24.9 A	398.3 A	43.3 A	13.6 A
Conventional	14.6 B	363.8 A	32.2 B	B
- - - Ratoon crop - - -				
Cutting Technique:				
Salibu system	11.2 a	216.9 a	30 a	8.2 a
Non-*salibu* system	8.5 b	165.1 b	18.6 b	5.4 a
Cultivation Methods:				
SRI	12.4 a	198.2 a	27.4 a	8.3 a
Conventional	7.4 b	183.8 a	21.2 b	5.3 b
Sources:				
- - - **Mean square** - - -				
Cutting	37.1 **	13411.0 *	640.3 *	37.4 ns
Cultivation	126.7 *	1038.2 ns	194.5 **	47.0 **
Cutting * Cultivation	4.1 ns	197.8 ns	57.9 ns	12.8 ns

Means followed by same upper-case letter within a column in the main crop are not significantly different at p=5% by t-test
Means followed by same lower-case letter within a column of each factor in the ratoon crop are not significantly different at p=5% by DMRT
Ratoon crop: * and ** are significant at p=1% and 5%, respectively; ns=non-significant at p=5%

Number of tillers and number of leaves per hill in the ratoon crop were affected by interaction between the treatment combination (cutting x cultivation) and the number of days. The number of tillers and number of leaves per hill using the ratoon crop were higher using the *salibu* system with the SRI method than using other treatment combinations. The number of ratooned tillers under the *salibu* system using SRI were 9, 19.3 and 23.8 at 15, 30 and 45 DAH, respectively (Figure 2a). In the *salibu* system using the SRI method, the number of leaves under ratooning at these same intervals were 16.6, 48.7 and 64.1, respectively (Figure 2b).

The number of productive tillers per hill and shoot dry weight was affected in the ratooned crop using the cutting technique and cultivation methods, being higher in the *salibu* system using the SRI method than in other treatment combinations. However, there was no interaction between the cutting technique and the cultivation methods. Root dry weight was also affected by the cultivation method, being higher with the SRI management than with the conventional practice. The number of productive tillers per m^2 was affected by the cutting technique as the number using the *salibu* system was higher than the number using the non-*salibu* system (Table 1).

Net Photosynthetic Rate

Table 2 shows that the net photosynthetic rate of the main crop using the SRI method was higher than that using the conventional method i.e. at peak vegetative and reproductive stages. The net photosynthetic rates of the main crop using the SRI method during the peak vegetative and reproductive stages were 40.1 and 29.1 µmol CO_2 m^{-2} s^{-1}, respectively, while those using the conventional method were 36.4 and 17.6 µmol CO_2 m^{-2} s^{-1}, respectively.

Similarly, the net photosynthetic rate of ratoon cropping was affected by the cultivation methods. The net photosynthetic rate of ratoon cropping using the SRI method was higher than that of the conventional method during both development stages (vegetative and reproductive). The net photosynthetic rate of the ratoon crop using the SRI method during the vegetative and reproductive stages was higher than that using the conventional method.

Table 2
Net photosynthetic rate during peak vegetative and reproductive stage at par of 2000 µmol photons m^{-2} s^{-1} *of main and ratoon crops*

	Net Photosynthetic Rate (µmol photons m^{-2} s^{-1})	
Main crop	Peak Vegetative Stage (70 Days After Sowing)	Reproductive Stage (90 Days After Sowing)
SRI	40.1 A	29.1 A
Conventional	36.4 B	17.6 B
	Net Photosynthetic Rate (µmol photons m^{-2} s^{-1})	
Ratoon Crop	Peak Vegetative Stage (35 Days After Harvest)	Reproductive Stage (60 Days After Harvest)
Cutting Technique:		
Salibu system	12. 8 a	9.9 a
Non-*salibu* system	13.1 a	9.9 a
***Cultivation Methods*:**		
SRI	13.7 a	10.5 a
Conventional	12.2 b	9.4 b
Sources:		
	Mean square	
Cutting	0.5 ns	0.0 ns
Cultivation	11.0 **	3.8 **
Cutting * Cultivation	1.2 ns	0.003 ns

Means followed by same upper-case letter within a column in the main crop are not significantly different at p=5% by t-test
Means followed by same lower-case letter within a column of each factor in the ratoon crop are not significantly different at p=5% by DMRT
Ratoon crop: * and ** are significant at p=1% and 5%, respectively; ns=non-significant at p=5%

Reproductive Growth

In the main crop, Table 3 shows that the grain dry weight per hill under the SRI method was higher than that of under the conventional method. Therefore, the SRI method was increased 119.3% of dry grain weight per hill. The weight of 1000 grains was also higher using the SRI method than using the conventional method. Grain dry weight at harvested per m^2 under the SRI method was higher than that using the conventional method. A similar trend was also observed for grain yield dry weight per m^2. The SRI method significantly increased grain yield (approximately 24.2%) compared with the conventional method.

In the ratoon crop, Table 3 shows that the grain dry weight per hill, harvested grain dry weight per m^2 and yield grain dry weight per m^2 were affected by the cutting technique and cultivation methods i.e. with no interaction between the cutting technique and the cultivation methods. The results indicate that grain dry weight per hill, harvested grain dry weight per m^2, and grain yield dry weight per m^2 were all significantly higher under the *salibu* system with SRI method than in the other treatment combinations.

Table 3
Weight of 1000 grains, grain dry weight per hill, grain dry weight at harvested per m^2 ($g\ m^{-2}$) and grain dry weight (yield) per m^2 ($g\ m^{-2}$) of main and ratoon crops

Treatment	Weight of 1000 Grains (g)	Grain Dry Weight per Hill ($g\ hill^{-1}$)	Grain Dry Weight at Harvested per m^2 ($g\ m^{-2}$)	Grain Weight (yield) per m^2 ($g\ m^{-2}$)
Main crop				
SRI	25.6 A	50.4 A	786.7 A	689.7 A
Conventional	24.1 B	23 B	633.4 B	555.4 B
Ratoon crop				
Cutting Technique:				
Salibu system	23.8 a	24.1 a	338 a	296 a
Non-*salibu* system	23.5 a	11.1 b	193.0 b	168.5 b
Cultivation Methods:				
SRI	23.7 a	20.7 a	312.5 a	273.5 a
Conventional	23.6 a	20.7 b	218.5 b	191 b
Sources :				
Mean square				
Cutting	0.7 ^{ns}	5845.9 *	105052.5 *	81217.5 *
Cultivation	0.04 ^{ns}	189.4 **	44227.0 *	34072.5 *
Cutting * Cultivation	0.5 ^{ns}	30.9 ^{ns}	2132.1 ^{ns}	1647.1 ^{ns}

Means followed by same upper-case letter within a column in the main crop are not significantly different at p=5% by t-test
Means followed by same lower-case letter within a column of each factor in the ratoon crop are not significantly different at p=5% by DMRT
Ratoon crop: * and ** are significant at p=1% and 5%, respectively; ns=non-significant at p=5%

Percentage of Ratoon Crop's Productivity Compared to the Main Crop

The data indicated that the rice plants' productivity under the *salibu* system using the SRI method was 50.3 % of that produced from the main crop (SRI vs Conventional) (Table 4).

Table 4
Percentage of ratoon crop productivity compared to main crop yield

Productivity of the Main Crop	Productivity of the Ratoon Crop	Ratoon Crop Compared with Main Crop
Conventional Method ($633.4\ g\ m^{-2}$)	Conventional x *salibu* ($280.6\ g\ m^{-2}$)	44.3 %
	Conventional x non-*salibu* ($156.3\ g\ m^{-2}$)	24.7 %
SRI Method ($786.7\ g\ m^{-2}$)	SRI x *salibu* ($395.4\ g\ m^{-2}$)	50.3 %
	SRI x non-*salibu* ($229.7\ g\ m^{-2}$)	29.2 %

Internal Carbohydrates and Phytohormones in the Rice Plant's Intercalary Meristem Tissue

Table 5 shows that the cutting technique affected the internal carbohydrates, gibberellins and cytokinins in intercalary meristem tissue, while the auxins were affected by the cultivation methods in the ratoon crop. The internal carbohydrates measured in the non-*salibu* system using the cutting technique were higher than those measured in the *salibu* system. Gibberellins and cytokinins measured in the *salibu* system were significantly higher than those measured in the non-*salibu* system. In addition, auxins were significantly higher in the SRI method than in the conventional method.

Table 5

Effects of cutting technique and cultivation methods on internal carbohydrates and phytohormones (such as gibberelins, cytokinins and auxins) in the rice intercalary meristem

Ratoon Crop	Internal Carbohydrates (%)	Gibberellins (ppm)	Cytokinins (ppm)	Auxins (ppm)
Cutting Technique:				
Salibu system	4.5 b	69.3 a	5.4 a	0.9 a
Non-*salibu* system	8.7 a	29.9 b	3.8 b	1.3 a
Cultivation Methods:				
SRI	6.6 a	57.7 a	4.8 a	1.4 a
Conventional	6.6 a	41.5 a	4.3 a	0.8 b
Sources :				
	---------- **Mean square** ----------			
Cutting	54.1 *	7772.6 *	14.0 **	0.9 ns
Cultivation	0.009 ns	1313.8 ns	1.3 ns	1.6 *
Cutting * Cultivation	0.4 ns	455.9 ns	1.2 ns	0.13 ns

Means followed by same lower-case letter within a column of each factor in the ratoon crop are not significantly different at p=5% by DMRT

Ratoon crop: * and ** are significant at p=1% and 5%, respectively; ns=non-significant at p=5%

DISCUSSION

Farmers practise leaving their paddy land unused after harvesting, thereby diminishing the value of land productivity. However, with some effort, they can rake in additional benefits from a following ratoon crop. Olivier et al. (2014) confirmed that the success of a ratoon crop depends on the prior success of the main crop. In this study, it was seen that vegetative and reproductive growth of the main crop using the SRI method was significantly higher than that seen using the conventional method. The number of leaves and tillers was higher using the SRI method. Transplanting young seedlings at 10 DAS for the main crop is advantageous for early crop establishment and for reducing the stress to the transplanted rice plants (Stoop et al., 2002). Ramli et al. (2012) reported that care for roots can minimise stress to the plant when tranplanting seedlings at 10 DAS, increasing crop stalks and roots during vegetative growth. A wide planting space reduces competition among plants for nutrients, water, light and air, which are all important for improving individual hill performance using the SRI method (Thakur et al., 2010).

This study also indicated that the SRI method was capable of increasing shoot and root dry weight. The photosynthetic rate of the main crop was also higher using SRI than using the conventional method, and this was responsible for converting most of the tillers to productive tillers. In addition, the SRI-grown plants were also capable of increasing reproductive growth such as the number of productive tillers, the weight of 1000 grains, grain dry weight per hill, grain dry weight at harvest per m^2 and grain yield dry weight per m^2. Thakur et al. (2011) have confirmed that morphological and physiological characteristics of rice plants using SRI were more conducive for increasing grain yield than using the conventional methods.

This study has confirmed that the number of tillers and productive tillers was generally lower in a ratoon crop than in the main crop. Oad et al. (2002a) confirmed that the morphology and productivity of ratooned rice plants differred significantly from those of the main crop. Other reports (Chauhan et al., 1985; Liu et al., 2012; Sanni et al., 2009; Tari, 2011) also have shown ratoon yields were lower than those of the main crop. However, with the *salibu* system of harvesting that used the SRI method, a ratoon crop could produce more productive regrowth at the vegetative to reproductive stages, thereby making crop performance higher than with the non-*salibu* management commonly practised by farmers.

Furthermore, the *salibu* system in combination with the SRI method for a ratoon crop increased the number of tillers per hill and the number of leaves. Ratoon tiller regeneration and growth depend on the buds that remain on the stubble of the stalks (Oad et al., 2002a). The height of stalk-cutting determines the number of buds regrown, stimulates dormant buds to grow and consequently, affects the number of tillers and grain yield (Harrell et al., 2009). In this study, the combination of the *salibu* system and the SRI method was capable of increasing the number of productive tillers per hill and shoot and root dry weights per hill of ratooned rice.

A similar trend to that of the main crop, the net photosynthetic rate of the ratooned crop during its peak vegetative and reproductive stages also was higher with the SRI method. However, the net photosynthetic rate in the ratoon was much lower than in the main crop. The combination of the *salibu* system and the SRI method was also capable of increasing grain dry weight per hill, harvested grain dry weight per m^2 and yield grain dry weight per m^2 compared with other cultivation and cutting combinations. In this study, the cutting techniques and cultivation methods increased the percentage of second-crop productivity measured relatively to its respective main crop. This was higher using the combination of *salibu* system and SRI method than using other treatment combinations.

The higher ratoon rice productivity achieved using the combination of the *salibu* system and the SRI method was determined by examining the growth and physiological effects of the rice stalk re-cutting at seven days after main crop harvesting. Ichii (1983) confirmed that the rice plants' ability to produce ratoon is influenced by internal and external conditions affecting the stubble and roots of rice plants. These include genetic traits, environmental conditions, water availability, soil fertility, sunlight, temperature, pests attack, plant diseases and the height of cutting (Mahadevappa et al., 1988).

The vigour of the root systems and high carbohydrate concentration in the stubble are prerequisites for the development of a ratoon crop after the main crop has been harvested (Oad et al., 2002a, 2002b). This study's results indicated that the cutting technique used for a ratoon crop affected the internal carbohydrates in intercalary meristem tissue after the main crop was harvested. The concentration of internal carbohydrates in the intercalary meristem tissues was found to be higher under the non-*salibu* system after harvesting than that of the *salibu* system. Stubble from the main crop harvested using the *salibu* system were re-cut 5 cm above the ground on the seventh day after the main crop was harvested, depreciating carbohydrate content in the stalks. The depreciating CH_2O had a positive effect on tiller regrowth in the ratoon crop. Due to the fact that carbohydrate residue in the stubble and roots had translocated to initiated buds that produced new tillers in the ratoon crop, the carbohiydrate content in the stalks had depreciated.

The re-cutting process stimulates the growth or regrowth of shoots that can increase the number of tillers and leaves in the ratooned rice plant. Carbohydrate residue in the stubble and roots is translocated to initiate buds that produce new tillers. The proportion of plant material (photosynthate reserves) in the ratoon roots and stalks affects the growth of the plants that will emerge from the internodes. If there are adequate photosynthetic reserves to be re-assimilated in the stalks and the stalks still have the ability to sprout, then the ratoon shoots will start to appear on the second to 10th day after the main crop harvest (De Datta & Bernasor, 1988). Following re-cutting, sunlight will then control the cell division process and plant elongation (Okello et al., 2015), and eventually new shoots will be initiated.

In addition, the *salibu* system affects phytohormones. Phytohormones have a critical role in the formation of new shoots. Kurepin et al. (2007) reported that shoot growth is affected by interaction between the environment and plant growth regulators. The *salibu* system is capable of increasing gibberellins and kinetins, a class of cytokinins, in the intercalary meristem of rice plants. It influences the number of new shoots more than in the non-*salibu* system. New shoots of ratoon crops emerge from the intercalary meristem tissue in internodes. The intercalary meristem tissue consists of the cells that are active to divide and grow. This tissue is the target of gibberelline to stimulate rice-stem elongation (Taiz & Zeiger, 2010). Gibberellins have a role in the process of cell enlargement, development and division in plants (Mahmoody & Noori, 2014) as well as in controlling stem elongation, germination and the transition from vegetative growth phase to reproductive phase (Thomas et al., 2005). Likewise, cytokinins have a role in triggering cell division and controlling the growth of shoot and root meristem tissue (Kyozuka, 2007).

In this study, auxins in the intercalary meristem tissue were affected by the cultivation method and they were significantly higher with the SRI method than with the conventional method. Auxins are produced in active meristematic tissue such as found at the tip of roots and shoots (Takahashi, 2013). Hidayati et al. 2016 comfirmed that the application of the SRI method had resulted in longer roots and heavier root biomass compared with the conventional method. The SRI method makes soil more favourable for aerobic activity and conditions that promote greater root growth. The biosynthesis of auxins is influenced by the oxygen level (Dai et al., 2013). The transport of auxins requires energy from the processes of metabolism, and their movement is hampered when oxygen is lacking (Taiz & Zeiger, 2010). The auxins in intercalary meristem tissue using the conventional method were lower compared with using the SRI method. This was caused by continuous flooding practised in the conventional method that led to the reduced oxygen.

CONCLUSION

The main crop yielded using the SRI method had a significantly higher net photosynthesis rate and vegetative and reproductive growth compared with the conventional method. The yield achieved using the SRI method across the cultivation method was higher by 24% than that achieved using the conventional method. The ratooned crop in the *salibu* system in combination with the SRI method had a higher net photosynthetic rate and vegetative and reproductive growth than that in the other treatment combinations. The ratoon crop had a much lower net photosynthetic rate than the main crop. This was the possible main reason for the lower yield in the ratoon compared with the main crop. Grain yield achieved using the *salibu* system and the SRI method was higher, attaining approximately 50.3% of SRI main crop yield that was higher than in other treatment combinations. Furtheremore, a better yield of ratoon crop may be achieved by increasing fertilisers (especially nitrogen) that may increase vegetative regrowth of the ratoon, balancing top vegetative growth to the stubble and rooting system left over by the main crop. Thus, the net photosynthetic rate can be increased in the ratoon. The inclusion of higher fertiliser application rate (especially nitrogen) for the ratoon could be included in future research looking into ways to improve this innovation. Higher levels of internal carbohydrates conserved in the intercalary meristem of the main crop stubble and phytohormones such as gibberellins, cytokinins and auxins in this biomass significantly influenced the main rice crop's ability to produce a successful and productive ratoon crop.

ACKNOWLEDGEMENT

The authors wish to thank the DIKTI (Directorate General of Higher Education) for the award of the Interior Graduate Education Scholarship (BPPDN) Candidate Lecturer 2013, Indonesia, and for providing financial support for this research. We would also like to thank Prof. Norman Uphoff of Cornel University, USA, for assisting in the correction of the manuscript draft.

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