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ARTICLE

Effect of intermittent irrigation following the system of rice intensification (SRI) on rice yield in a farmer's paddy fields in Indonesia

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Abstract

System of rice intensification (SRI) has been disseminated in many countries because of its high yield, although the mechanism of yield increase has yet to be fully understood. The aims of this study were to clarify the actual water management of a skilled SRI farmer in irrigated paddy field of Indonesia and to examine the effect of intermittent water management on rice growth and yield. Yield and yield components were compared in the field experiments in the farmer's fields under intermittent (SRI) or flooded (FL) irrigation for 4 years from 2013 to 2016. The daily mean water depth of SRI plots during 0–40 days after transplanting showed very shallow (ca. 2 cm) or little lower than soil surface and continued to be lower than soil surface during reproductive stage when panicles were formed. The yield of SRI significantly exceeded that of FL for 4 years by 13% ($P = 0.0004$), so did the panicle numbers per area ($P = 0.036$). The yield increase in SRI was associated with the increased number of panicles, which should have resulted from enhanced tiller development under shallow water level during the vegetative stage. The increased number of panicles was, however, counteracted by the reduced number of spikelets per panicle and resulted in nonsignificant increase in the spikelet density, defined as number of spikelets per unit area of crop. This dampening change in spikelet number per panicle could have been caused by limited supply of either nitrogen or carbohydrate during the panicle development stage under the intermittent water supply. A greater yield increase by SRI could be expected by improving nutrient or water management during the reproductive stage.

Keywords Intermittent irrigation · Flooding · Yield component · Growth stage

Introduction

Rice, the primary staple food for Indonesia's 250 million people, provides seasonal income and employment for a large segment of the country's rural population. Significant growth in rice production has bolstered rural development since the early 1970's, but climate change has negatively affected rice production in Indonesia with El Nino/Southern Oscillation (ENSO) events as reported in previous studies (Yokoyama 2003; Nugroho 2016). Climate change caused the increased scarcity of and competition for water resources changing the planting pattern in Indonesia (Nugroho 2016; Irawan 2002). As a result, declining trend in grain yield by 1% annually during 2010–2050 is estimated, particularly in Java island (Amien et al. 1996). Therefore, adaptation strategies to climate change in Indonesian rice farming are needed for dealing with this situation. Water saving technology has become one of the priorities in rice research (Barker et al. 2000). From previous findings, rice can be produced under

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water saving regimes of system of rice intensification (SRI) in which continuous flooding irrigation is no longer essential to gain high yields and biomass production (Lin et al. 2011; Sato et al. 2011; Zhao et al. 2011).

SRI is well known for raising the productivity of rice by adopting a set of practices for managing plants, soil, water, and nutrients (Kassam et al. 2011; Uphoff et al. 2011). It is an alternative rice cultivation which could be useful to adapt to climate variability, especially to frequent drought by less consumption of irrigated water. The principle of SRI is growing rice with the use of nursling seedlings by transplanting with wide spacing, intermittent irrigation and several weeding during the early growth stage, which sometimes realize considerably high yield compared to conventional continuous flooding (Uphoff et al. 2011). Although many farmers as well as researchers have been trying to achieve high yield by SRI in a stable manner, accomplishment is not as desired due to various constraints. One of the constraints is lack of sufficient water supply in rainfed rice areas. Rice farmers in a rainfed district of south Cambodia cannot fully adopt SRI because of the limited availability of supplementary water for timely SRI water management (Lee and Kobayashi 2017, 2018).

In contrast, in irrigated paddy agriculture, adoption of SRI by rice farmers does not suffer directly from lack of water supply but that of standardization in water management techniques. The water resources for irrigation have also become tighter due to the unpredictable rain falls under global climate change.

Our aims in this research were

1. to clarify the actual situation of water management (intermittent irrigation) which enabled the higher yield of rice compared to conventional continuous flooded management at the on-site experiment in the study village,
2. to examine the effect of the intermittent irrigation on growth and yield as compared to flooded management, and
3. to propose any improvements over the water management adopted by the farmers.

Materials and methods

Research site

The research was conducted in the period from 2013 to 2016 in Gemawang village, Girimarto, Wonogiri District, Central Java Province, Indonesia (7°47′19.7″S, 111°05′50.4″E) (Fig. 1). The research site was located in hilly topography at about 500 m ASL. SRI was introduced to this village around 2008, and the farmers grew rice with SRI for two or three crops annually since then. They had therefore experienced 12–18 crops of rice cultivation with SRI as of 2013.

Preliminary interview to the villagers

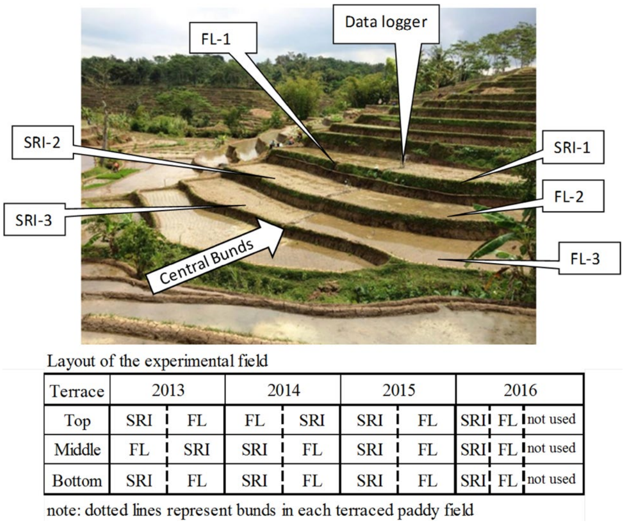
Interview survey was carried out in 2013 to 49 farmers, some of whom had adopted SRI. Hand-drawn hydrograph by each farmer was digitalized and analyzed by using water index (WI) which is the product of water depth and submergence days. Regression analysis was carried out to find a relationship between WI and rice yield reported by the farmers.

Experiment in a farmer's fields

We conducted an experiment in paddy fields of a skilled SRI farmer in Gemawang village from July or August to November (dry season) across 3 years from 2013 to 2015, and from April to July (dry season) in 2016. We chose this

Fig. 1 Map of study site at Gemawang village, Girimarto, Wonogiri District in Central Java

farmer because he had recorded a very high yield (12 t ha^{-1} of rough rice) in 2009 (Yokoyama personal communication). The test fields were planted to rice three times a year, namely April–July, July (or August)–November, and December–April during the experimental period. We used three consecutive terraced fields, each of which had area of 100–150 m^2, for the field experiment. Paddy soil belongs to Gleysols (soil taxonomy by FAO) with a texture of light clay and TC of 17.7 and TN of 1.62 g kg^{-1} with available N of 208 mg kg^{-1} after 4 weeks submerged incubation at 30 °C. Each terraced field was split into flooded plot (FL) and intermittent irrigation plot (SRI) by a bund built at the center of the field. In the latter plot, we asked the farmer to apply the water management following SRI practices, whereas we asked him to keep the latter plot continuously flooded. See Fig. 2 for the layout of the experimental fields.



Layout of the experimental field

Terrace	2013		2014		2015		2016		
Top	SRI	FL	FL	SRI	SRI	FL	SRI	FL	not used
Middle	FL	SRI	SRI	FL	SRI	FL	SRI	FL	not used
Bottom	SRI	FL	SRI	FL	SRI	FL	SRI	FL	not used

note: dotted lines represent bunds in each terraced paddy field

Fig. 2 Experimental fields with the bunds in the center of each terrace (2014) and the layout of the field from 2013 to 2016

All other managements were practiced in the same way across the plots. The farmer incorporated all harvested rice straw into the soil when plowing. Amount and timing of fertilizer application were left to the farmer's decision and the other crop managements, e.g., transplanting young seedlings with few plants per hill at a greater-than-conventional spacing (25 cm by 30 cm or 30 cm by 30 cm), several hand weeding during vegetative stage were almost the same as the standard SRI practice (Table 1). Pest insects were controlled using pesticides as needed.

Measurements of water depth and soil moisture status

The water depth was measured by HOBO water depth logger (U20-001-04S, Onset computer corp.) at an hourly interval. The logger with a pressure sensor inside was inserted in a perforated PVC pipe and installed in the ditch surrounding each plot along with a reference logger in the perforated PVC pipe set at 20 cm above the ground in the same field. Water depth was also measured by taking pictures of a scale inserted in the soil of each plot almost every day to collate with the water depth measured by the loggers. Besides those measurements, the farmer recorded the observed state of soil moisture in the fields almost every day using three scores: no

Table 1 Crop calendar and management for 2013–2016

	2013[a]	2014	2015	2016
Rice variety	Ciheran	IR-64	Ciheran	Ciheran
Seedling [days after sowing, (leaf age)]	13 days (4.5)	14 days (4.2)	20 days (5.5)	15 days
Date of transplanting	20 July	20 July	5 August	11 April
Date of heading	15 October	8 October	25 October	18 May
Date of harvest	19 November	7 November	13 November	21 July
Total growing days	121	109	100	102
Spacing (cm × cm)	30 × 30	25 × 30	25 × 30	25 × 30
N application (g m^{-2})				
Basal *N*				
Organic	0.8	0	3.75	2
Inorganic	0	4.5	0.5	6
Topdressing *N*				
Inorganic	13.8[b]	0	0	0
Liquid fertilizer	0	0.01	0.01	0.01
Total *N* (g m^{-2})	14.6	4.51	4.26	8.01

[a] 2013 was unusual year with delayed heading by insect damage in early vegetative stage

[b] Top dressing N was applied at 4.5 g m^{-2} on 16 days after transplanting (DAT) and at 9.3 g m^{-2} on 37 DAT

water on the soil surface as 1, some water still remains on the soil surface as 2, and flooded soil surface as 3.

Measurement of rice plant growth and yield

Growth of rice was measured at maturity stage. In each plot, an area with average growth was selected and consecutive 10 hills in two rows, total of 20 hills were measured for their heights and panicle numbers. Five hills near average panicle numbers were sampled in each plot. After measuring the fresh weight, panicles were separated from the plants and the number of spikelets was measured. In 2015, dry weight was measured after oven-drying at 80 °C and N content was determined by Sumigraph NC-200F (Sumitomo Chemicals Co. Ltd.). Yield measurement was taken for a 5-m^2 area with 3 replicates in 2013 and 2016, and for 12 hills (about 1 m^2) with 3 replicates in 2014 and 2015. Grain yields were calculated after corrected for water content of grains to 15%.

Statistical analysis

Statistical analysis was performed with JMP Pro version 13.0.0 (SAS Institute, Cary, USA) on replicate means unless noted otherwise. For observations conducted across four (2013–2016) or three (2013–2015) years, mixed linear models were fit to rice growth parameters and yield with replicate being designated as a random effect and the effects of year, water management practice, and their interaction being fixed effects. Relationships between rice growth parameters and nitrogen (N) uptake were analyzed with general linear models on the measurements of individual hills in 2015, which is the only year when N content in rice plants was measured.

Results

Relationship between irrigation water depth and yield at the target village

The rice yield in the interview survey was negatively correlated with the ponding water index (WI) ($P = 0.033$), which suggests a favorable effect of irrigation with lower water depth on rice yield (Fig. 3).

Water management and nutrient management of a skilled SRI farmer and its characteristics

The daily mean water depth of SRI and FL plots for 2013–2015 is shown in Fig. 4. The daily mean water depth in SRI plots during 0–40 days after transplanting (DAT) was very shallow (ca. 2 cm) or little lower than soil surface and continued to be lower than soil surface during reproductive stage when panicles were formed. The FL plots were intended to be kept flooded continuously; however, the water level fluctuated and sometimes became below soil surface as shown in Fig. 4, suggesting the incidental loss of ponding water through cracks in bunds or by percolation. The water depth measurement was complemented with the farmer's daily observations of the soil moisture status, which suggested that FL plots were mostly submerged and SRI plots were mostly wet or shallow submerged but not dried at all (Fig. 5). Hourly water depth showed diurnal fluctuation of water depth at 2–6 cm in both FL and SRI plots in 2014 (Fig. 6). In SRI plots, the hourly water depth rarely exceeded soil surface during and after the reproductive stage, whereas, in FL plots, it was mostly kept higher than soil surface. The SRI water management of this farmer is characterized by the shallow submergence or saturated moisture during vegetative stage during 30–40 DAT followed by much lower water depth with drier soil surface by frequent intermittent irrigation during the reproductive stage and thereafter.

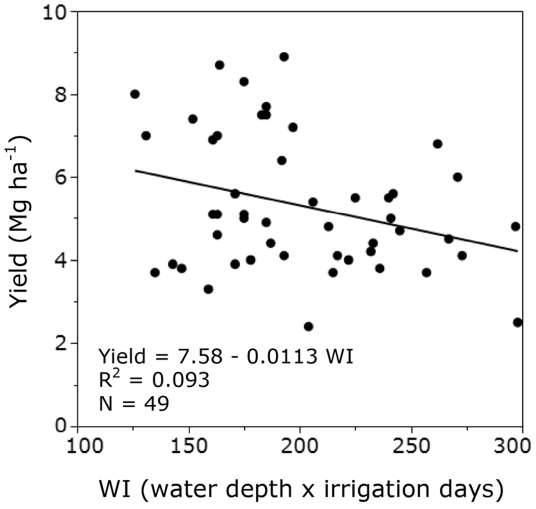


Fig. 3 Correlation between water index (WI) and yield reported by farmers

Effect of water management on rice growth and yield

Intermittent irrigation in SRI plot significantly increased grain yield ($P = 0.0004$) in 2013–2016 without a significant interaction with year ($P = 0.220$) (Table 2). Panicle number was significantly increased by SRI ($P = 0.036$), whereas number of spikelet per panicle was significantly reduced by SRI ($P = 0.029$) in 2013–2015 (Table 3). These two changes due to SRI water management canceled each other resulting in nonsignificant increase in spikelet density ($P = 0.311$). When numbers of panicles and spikelet

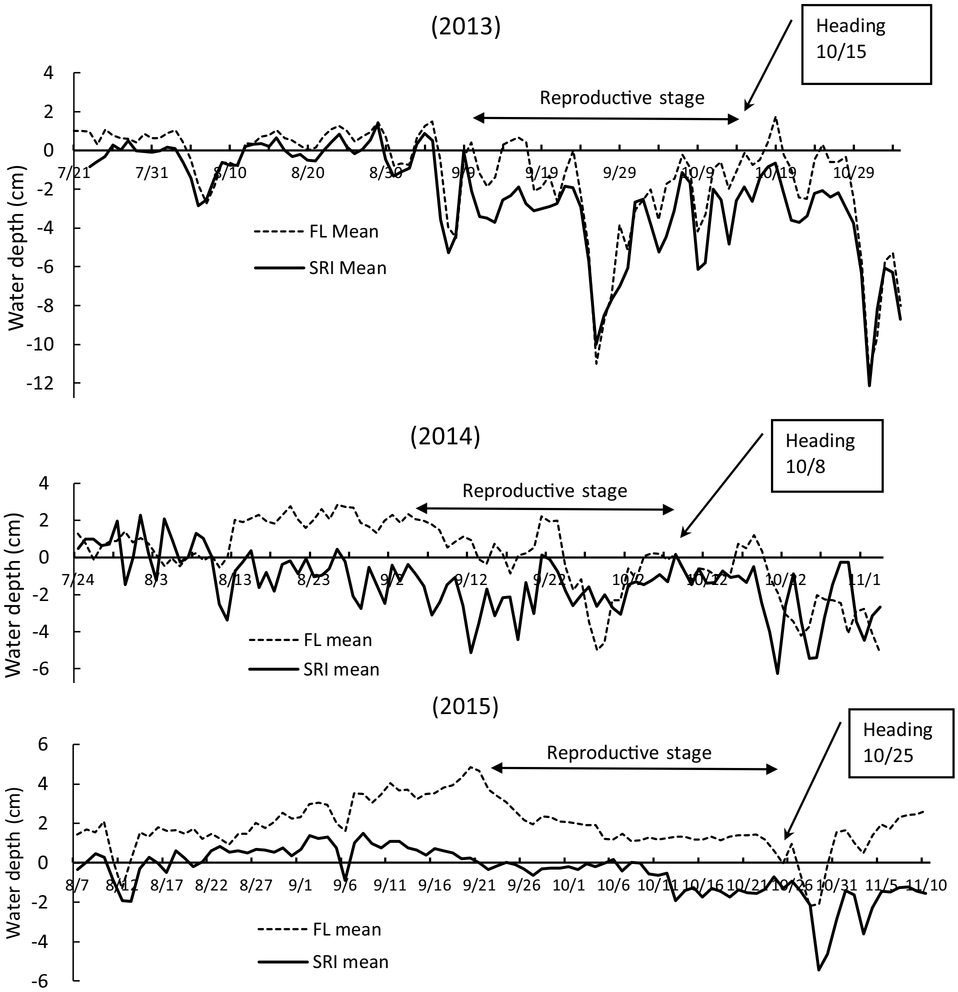


Fig. 4 Daily mean water depth of FL and SRI plots ($n = 3$ for each treatment)

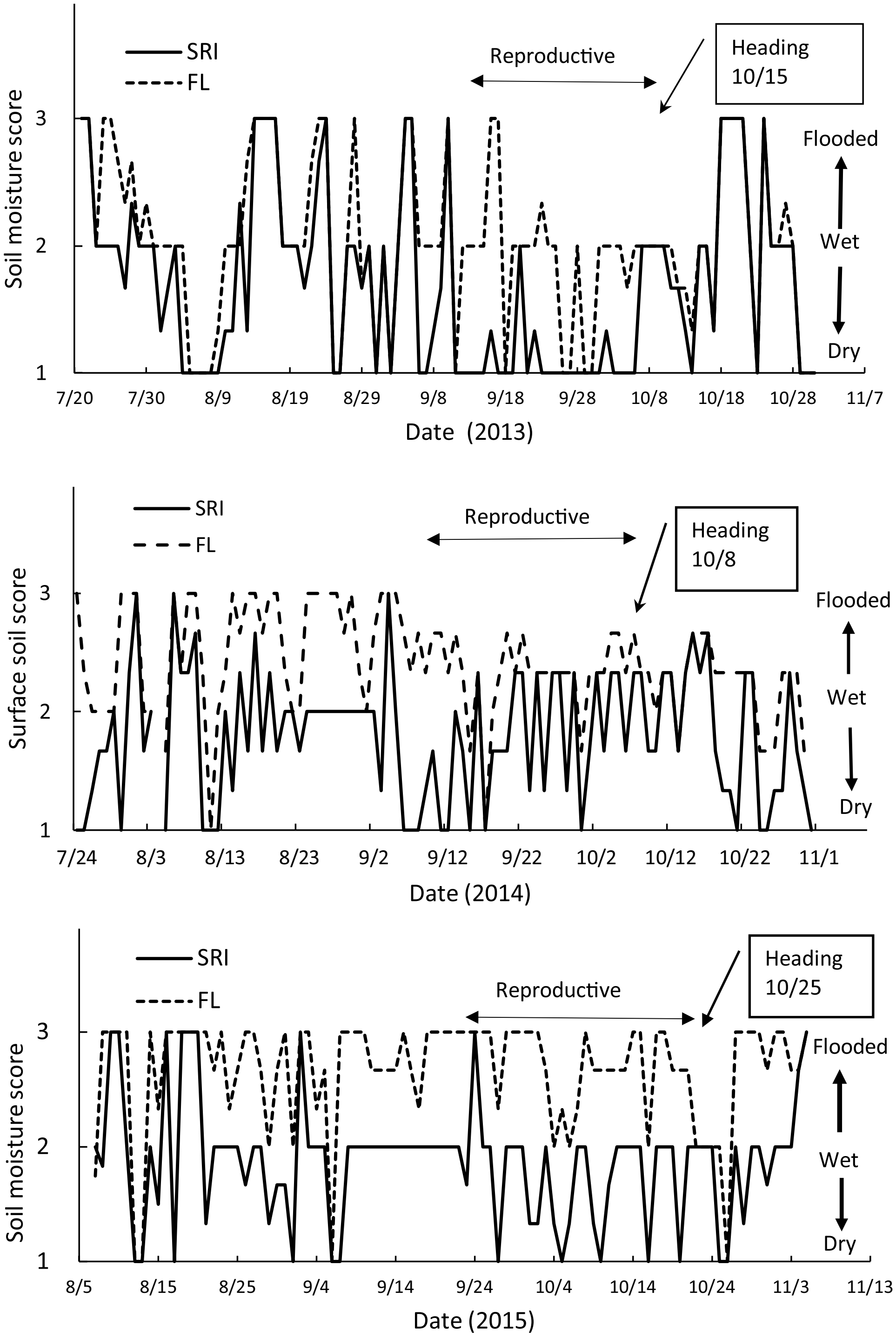
density were plotted against the amount of N accumulated in plants at harvest in 2015, they showed close relationships (Fig. 7), whereas the effect of water management on number of panicles (Fig. 7a) somewhat differed from that on spikelet density (Fig. 7b). Number of panicles was increased by SRI ($P = 0.002$) independently from the effect of increasing N accumulation ($P < 0.001$) with the interaction between the two being nonsignificant ($P = 0.685$) (Fig. 7a). In comparison, water management had no significant effect on spikelet density ($P = 0.569$), whereas its interaction with N accumulation at harvest was highly significant ($P = 0.005$). On the same N accumulation, the rice plants in SRI tended to have lower spikelet density than those in FL (Fig. 7b). A similar tendency was found in the relationship between total aboveground biomass at harvest and grain biomass in 2015 (Fig. 8). The relationship significantly differed between SRI and FL water managements ($P < 0.001$), and relative to a greater biomass at harvest, the rice plants in SRI tended to have less grain mass than those in FL (Fig. 8).

Discussions

Water management by the SRI farmer and the paddy water regime

In SRI, it is recommended to drain water shortly after transplanting, keep soil wet but not submerged during vegetative stage, and maintain a water layer of 1–2 cm after panicle formation (Uphoff et al. 2011). In this study, the farmer kept the soil wet or submerged during vegetative stage and enhanced the drainage at about 30–40 days after transplanting onward, which was about the beginning of the reproductive stage (Fig. 4). In addition, hourly water depth during cropping season indicated the large fluctuations ranging from 2 to 6 cm in a day (Fig. 6). The surface soil moisture of SRI plot visually scored by the farmer showed saturated soil condition throughout the cropping season even in non-submergence period after reproductive stage (Fig. 5). The paddy water regime thus described should be conducive to high yield as suggested by the negative correlation between the yield and WI (water index) as shown in Fig. 3.

Fig. 5 Observed status of soil moisture for FL and SRI plots in 2013 (mean of 3 replicates). *Note* soil moisture score; 1 = no water on soil surface, 2 = some water remains on soil surface, 3 = flooded



Effects of water regime on rice growth, *N* accumulation and grain yield

The field experiment across 4 years confirmed the yield increase by the farmers' intermittent irrigation as compared with continuous flooding (Table 2). The analysis of yield components for 3 years indicated the increased number of panicles as the major contributor to the yield increase, while it also suggested a negative effect on the number of spikelet per panicle leading to the only nonsignificant increase in the spikelet density (Table 3).

In the literature also, both negative and positive effects of intermittent irrigation on rice growth and yield have been reported (Bouman and Tuong 2001; Yang et al. 2004; Won et al. 2005; Belder et al. 2005; Menete et al. 2008; Chapagain and Yamaji 2010; Lin et al. 2011). Menete et al. (2008)

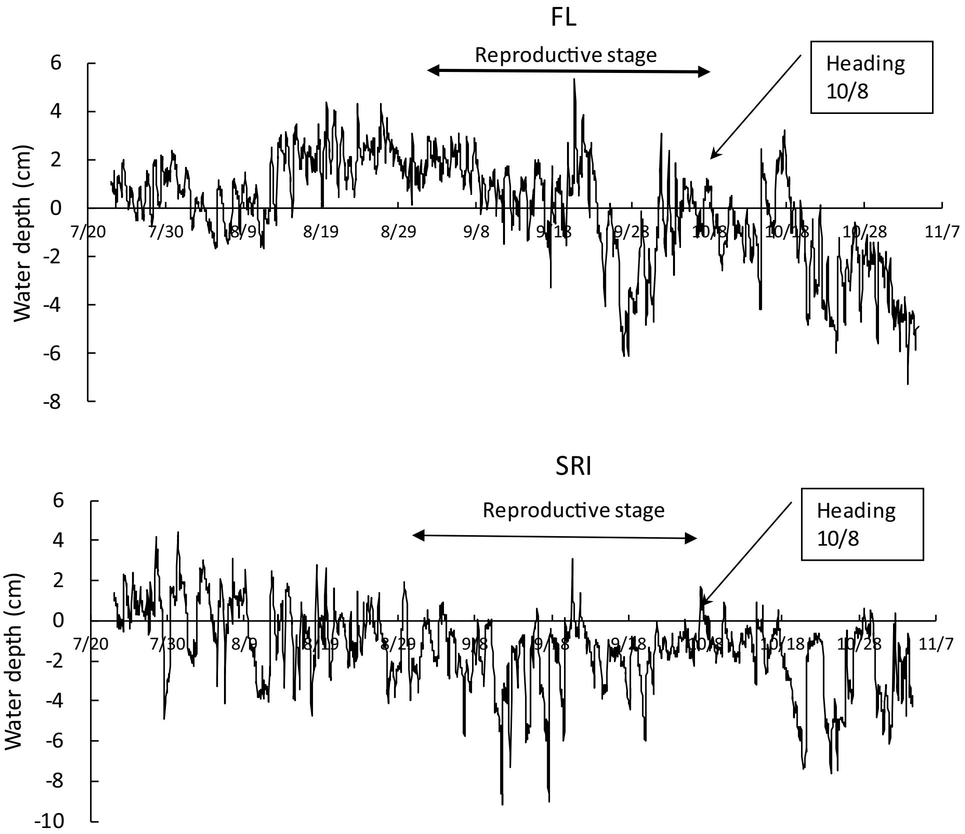


Fig. 6 Hourly mean water depth of FL and SRI plots in 2014 ($n=3$). *Note* mean water level was calculated from 3 values obtained from each plot

Table 2 Rough rice yield in dry seasons of 4 years from 2013 to 2016 (g m^{-2})

Irrigation	2013	2014	2015	2016	Mean	CV(%)
SRI	1202	774	878	922	944	19.4
FL	1111	729	746	770	839	21.7
SRI/FL (%)	108	106	118	120	113	

P values for the effects of water management, year, and their interaction were 0.0004, <0.0001, and 0.220, respectively

Table 3 Effect of irrigation regime on yield and yield components across 2013–2015

Irrigation	Yield g m^{-2}	Panicles m^{-2}	Spikelets per panicle	Spikelet density m^{-2}
SRI	951	366	111	40,180
FL	862	334	118	38,690
Effect ($P=$)	0.009	0.036	0.029	0.311

As grain numbers were not measured, data of 2016 were omitted from the mean

reported significant yield reduction under intermittent irrigation regime with no synergistic effect being found with other SRI components. Factorial analysis by Chapagain and Yamaji (2010) showed higher grain yield under flooded condition than intermittent irrigation starting 15 days after transplanting. Belder et al. (2005) focused on the strength of water stress under intermittent irrigation with the minimum water potential of −30 kPa (pF = 2.5) and −50 kPa (pF = 2.7) at 20 cm soil depth and found no yield difference between them. They also compared continuously flooded with intermittent irrigation regimes, but found no significant yield difference.

On the other hand, Lin et al. (2011) revealed that LAI and dry matter production increased under aerobic irrigation with no standing water in the field during the vegetative growth stage. In a meta-analysis of the effect of irrigation regime on rice yield and water productivity, however, Bouman and Tuong (2001) showed a larger influence of drought at vegetative stage than reproductive stage. This was because of the considerable decrease in tiller number due to water stress during the vegetative stage and the resultant decrease in yield potential probably via decreased leaf area. Yang

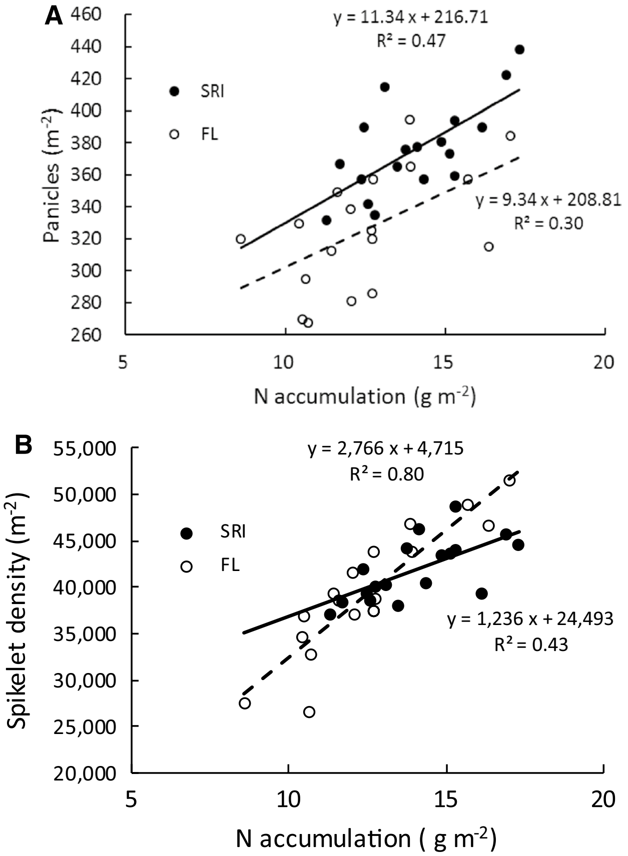


Fig. 7 Relationship between plant *N* accumulation at harvest and number of panicles (**a**) and spikelet density (**b**) for SRI and FL treatments in 2015

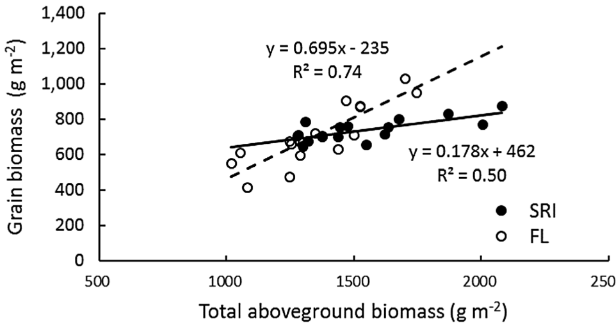


Fig. 8 Relationship between total aboveground biomass at harvest and grain biomass in 2015

et al. (2004) reported a superior condition for rice root growth under alternately flooded condition than continuously flooded one in terms of root morphology and physiology. Won et al. (2005) examined the effect of water depth of intermittent irrigation on rice growth and found more roots grown in deeper soil when irrigated at water depth below 2 cm. Mishra and Salokhe (2011) also indicated that intermittent irrigation during vegetative stage positively affected yield when followed by shallow flooded conditions in reproductive stage. The positive effect was not found, however, when intermittent irrigation was continued into reproductive stage. The literature thus seems inconsistent in the effect of intermittent irrigation on rice yield, whereas the importance has invariably been placed on the timing when the intermittent irrigation is performed in relation to the growth stages.

As noted earlier, in the rice paddies under intermittent irrigation in this study, the soil was kept wet or submerged during vegetative stage, and frequently drained around 30–40 days after transplanting, which was about the beginning of the panicle formation stage. Such water regime as compared with the continuous flooding could have caused the changes in rice growth and yield. The shallower water depth should have enhanced tiller development, which led to the greater number of panicles and eventually the higher grain yield (Table 3). The increase in the number of panicles did not, however, proportionally increase the grain yield since the number of spikelets per panicle was reduced by the intermittent irrigation canceling out the increase in the number of panicles (Table 3). The change in the number of spikelets per panicle could have resulted from constraint on either nitrogen accumulation or carbohydrate supply at the panicle formation stage.

According to the previous studies (Murayama 1969; Hasegawa et al. 1994; Horie et al. 1997), spikelet density is strongly linked to N accumulation at panicle formation stage. The lack of significant increase in spikelet density under SRI water management (Table 3) may therefore indicate no significant increase in N accumulation at the stage when spikelet differentiation took place. After that stage, further enhancement in N accumulation by SRI would not increase spikelet density, while increasing N amount at harvest as depicted in Fig. 7.

It has also been shown that spikelet density is determined by aboveground biomass at panicle formation stage (Hasegawa et al. 1994). If this was the case in this study, the reduction in the number of spikelets per panicle under intermittent irrigation may indicate water stress on carbohydrate supply to differentiated spikelets leading to increased spikelet degeneration during panicle formation stage. Subsequent increases in biomass accumulation due to SRI would have also led to the results shown in Fig. 8.

With the lack of measurements on plant growth and N accumulation at panicle formation stage, we cannot determine which of the above constraints, i.e., N or carbohydrates, was responsible for the reduced number of spikelets per panicle under SRI water management as observed in this study. If N was the prevailing constraint, nutrient management will have to be revised for taking better advantage of the increased number of tillers for a higher spikelet density and eventually a greater yield increase. If carbohydrate supply was the major constraint, on the other hand, the water management during the panicle development stage will have to be revised for a greater yield increase. In either case, an observation of N accumulation and plant growth at panicle development stage is critical in further studies to enhance the yield gain by SRI via water management.

Conclusions

Four years of on-site experiments confirmed the increase in rice yield due to intermittent irrigation under SRI as compared with the conventional flooded irrigation. The yield increase in SRI was associated with the increased number of panicles, which should have resulted from enhanced tiller development under shallow water level during the vegetative stage. The increased number of panicles was, however, counteracted by the reduced number of spikelets per panicle and resulted in nonsignificant increase in the spikelet density. This dampening change in spikelets number per panicle could have been caused by limited supply of either N or carbohydrate during the panicle formation stage under the intermittent water supply. More research is warranted with particular focus on water and nutrient managements during the panicle formation stage for taking better advantages of increased number of panicles leading to a further increase in rice yield in SRI.

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