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RESEARCH

Effects of straw returning on rice growth and yield under water-saving irrigation

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ABSTRACT

Straw returning (SR) is an important means of straw utilization, which has been tested and is helpful for improving soil fertility and crop production. However, the effects of SR on plant growth and yield of paddy rice (*Oryza sativa* L. subsp. *japonica* Kato) under water-saving irrigation (WSI) are rarely investigated. In the 2015 and 2016 rice seasons, field experiments were conducted with four treatments, namely controlled irrigation with conventional fertilization (CI-CF), controlled irrigation with straw returning (CI-SR), flooding irrigation with conventional fertilization (FI-CF), and flooding irrigation with straw returning (FI-SR). The objective of the present study was to investigate the response of plant height, number of tillers, biomass, and yield to SR and irrigation management. Results indicated that SR enhanced rice yield on average by 7.9% and 7.5% and improved irrigation water use efficiency (IWUE) by 6.3% and 8.3% in 2015 and 2016, respectively. The CI-SR combination significantly increased IWUE compared with FI-CF. These results suggested that SR could offset the inhibition of rice growth caused by CI, and the CI-SR combination could be an effective measure to enhance soil fertility, maintain the rice field, and increase IWUE. Furthermore, rice growth (plant height, number of tillers, and biomass) was slightly inhibited by SR during the first 20 d of the rice season, but increased after the jointing stage (approximately 40 d after transplanting). This implied that diverting some top-dressed chemical N fertilizer into basal application may be necessary for fertilizer management to better meet crop nutrient uptakes in rice fields with SR application, especially with CI.

Key words: Controlled irrigation, flooding irrigation, irrigation water use efficiency, *Oryza sativa*, soil available nutrients, straw returning, yield components.

INTRODUCTION

Crop straw is a large universal organic agricultural waste resource, which has exceeded 700 million tons per year in China and accounts for more than 25% of global straw resources (Lal, 2005; Yang et al., 2014). However, most crop straw is directly burned and only a small portion (2%-5%) is used as organic fertilizer for agricultural production (Yang et al., 2014), and it has inevitably caused wasted resources and environmental pollution (Thuy et al., 2008; Ge et al., 2013). Meanwhile, crop straw is a sustainable agricultural resource; it usually plays a positive role in maintaining soil fertility and improving soil characteristics (Liu et al., 2014a; Abrantes et al., 2018). Straw resources have been of greater interest in recent years, and their rational use and influence on agricultural production are key issues.

Straw returning (SR) is a direct and effective means of straw utilization; it not only offers an opportunity to consume crop straw, but also supplies organic matter (OM) for farmland and reduces the amount of chemical fertilizer (Sfez et al., 2017). Previous studies have researched the impact of SR on soil structure and OM decomposition, indicating that it is helps to decrease soil bulk density, increases soil water stable aggregates (Liu et al., 2014a), and improves soil organic matter (SOM) (Curtin and Fraser, 2003). Many studies have been concerned with the influence of SR on crop growth and yield (Asten et al., 2005; Kaur and Mahal, 2017; Wang et al., 2018). For paddy fields, previous studies have investigated the impact of the amounts, application time, and burial depth of SR on rice (*Oryza sativa* L.) growth and yield (Beutler et al., 2017; Mi et al., 2018). It has been demonstrated that SR at the rate of < 7.5 t ha^{-1} can enhance rice plant height, number of tillers, and biomass production in the middle or late growth stages (Thuy et al., 2008; Han et al., 2012). It can also reduce rice effective panicles per unit area, while number of spikelets per panicle, ripening rate, and rice yield can increase (Xu et al., 2015). The appropriate amount and burial depth of SR to increase rice yield have been at approximately 9 t ha^{-1} and 5-8 cm, respectively (Curtin and Fraser, 2003; Zhang et al., 2015). Although there is adequate information about the effects of SR on rice growth and yield, most studies have researched its impact under flooding irrigation (FI).

With irrigation water shortage on the increase and food security issues in China, water-saving irrigation (WSI) techniques (such as alternative irrigation, AI and controlled irrigation, CI) are being widely used in paddy fields (Bouman et al., 2007; Xu et al., 2017; Yang et al., 2018). Under WSI irrigation, soil moisture is different than under FI. This definitely leads to remarkable changes in soil aeration, soil microorganism properties, and thus crop straw decomposition, which could greatly influence rice growth and yield. However, only a few studies (Zhang et al., 2014; Zhao, 2016; Zhao et al., 2018) are dedicated to investigating the effects of SR on soil properties or rice growth under WSI conditions, and their conclusions are sometimes contrary one with the other. For example, Zhao (2016) demonstrates that SR under AI irrigation is more beneficial to reduce soil bulk density, increase soil total N and OM, and improve N utilization compared with FI, which usually leads to an increase in the number of spikelets per panicle, rice biomass, and yield. Zhang et al. (2014) have researched rice growth and yield under different irrigation (FI and AI) and straw utilization (returning or mulching) methods. They have indicated that AI irrigation can effectively mitigate the negative effects (usually reduced soil pH and soil aeration and increased reductive toxic substances) of SR and increase rice plant height, biomass production, and yield, independently of SR or straw mulching conditions. Zhao et al. (2018) have investigated rice growth and yield from SR in paddy fields with different irrigation regimes (FI, AI, and CI); they found that WSI (AI and SI) reduces rice plant height and yield (except for AI) compared with FI, although it usually accelerates SOM decomposition in straw and increases the number of tillers at the middle growth stage. Crop straw is an important source of SOM and is significantly affected by soil moisture. Therefore, rice WSI technologies should be applied in combination with SR to reveal the impact it has on rice growth and yield, especially compared with FI and conventional fertilization (CF) conditions. However, such combined applications have rarely been investigated in previous research studies.

A 2-yr field experiment was conducted in a paddy field with different water and fertilizer management. The objectives of the study were to investigate the impact of SR on crop growth under WSI as well as analyze and compare the effect of water and fertilizer management on rice yield and irrigation water use efficiency.

MATERIALS AND METHODS

Experimental design

The experiment was conducted from June 2015 to November 2016 in rice fields at the Kunshan Irrigation and Drainage Experimental Station (31°15'15" N, 121°57'43" E) in Tai Lake region, Jiangsu Province, China. The study area has a subtropical monsoon climate with an average annual air temperature of 15.5 °C and average annual precipitation of 1097.1 mm. The top (0-18 cm) soil is clay with 21.8 g kg^{-1} OM, 1.8 g kg^{-1} total N (TN), 1.4 g kg^{-1} total P (TP), 20.9 g kg^{-1} total K (TK), and pH 7.4 (1:2.5, soil:water). The mean saturated soil water contents for the 0-20, 0-30, and 0-40 cm layers were 54.4% (v/v), 49.7% (v/v), and 47.8% (v/v), respectively. The rice variety used in our experiment was *japonica* rice (*Oryza sativa* L. subsp. *japonica* Kato) Nanjing 46, which was transplanted with 13 cm × 25 cm hill spacing on 26 and 28 June in 2015 and 2016, and harvested on 30 October and 4 November in 2015 and 2016, respectively.

Two irrigation treatments were designed for the experiment, FI and CI, and two fertilization treatments, CF or SR. The four treatments were flooding irrigation with conventional fertilization (FI-CF), flooding irrigation with straw returning (FI-SR), controlled irrigation with conventional fertilization (CI-CF), and controlled irrigation with straw returning (CI-SR). A randomized complete block design was established in 12 plots of 150 m^2 (15 m length ×10 m width) for the four treatments with three replicates. The ridges, 300 mm wide at the base and 200 mm high, were covered with a plastic membrane that was inserted into the soil plough layer to a depth of 300 mm on both sides of the ridges to isolate water in different plots and prevent hydraulic exchange between adjacent plots.

For the FI treatment, a 3-5 cm standing water level was always maintained after transplanting (days after transplanting, DAT) except in the later tillering and yellow maturity stages. For the CI treatment, the water depth was maintained at 5-25 mm during the first 7-8 DAT in re-greening. At other stages, irrigation was applied to saturate the soil without flooding, except during the period of fertilization, herbicide, or pesticide application when 3-5 cm water was established in the rice field for 3-5 d. The maximum water depth after rainfall was set at 5 cm and maintained for less than 5 d. The soil moisture thresholds for CI at different growth stages can be found in another document (Yang et al., 2018).

The rate and split applications of inorganic fertilizers followed the suggestions made by the local Agro-Technical Promotion Station, which provided detailed recommendations for fertilization and pest control based on local weather, soil fertility, and crop growth. The total N, P, and K inputs during the whole rice growth stage were 283.4 kg N ha^{-1}, 54.0 kg P_2O_5 ha^{-1}, and 76.5 kg K_2O ha^{-1} in 2015, respectively, while they were 321.1 kg N ha^{-1}, 45.0 kg P_2O_5 ha^{-1}, and 63.8 kg K_2O ha^{-1} in 2016, respectively. Phosphorus and K compound fertilizers were applied as basal fertilization. The applied N fertilizers are listed in Table 1. The basal fertilizers were mixed into the muddy soil and all other fertilizers were manually transferred to the surface water. In addition to chemical fertilizers, 3000 kg ha^{-1} cut wheat straw was applied to the SR paddy fields in 2015 and 2016.

Field measurements

Irrigation water volumes were recorded with water meters installed on the pipes of each plot. Soil moisture was measured daily with three replicates using a time domain reflectometer (MiniTrase 6050X3, Soilmoisture Equipment Corp., SEC, Santa Barbara, California, USA) and 20 cm waveguides installed at 0-20 cm and 20-40 cm soil depth. Daily meteorological data (including precipitation volume, wind speed, temperature, sunshine duration, and relative humidity) were recorded with an automatic weather station (ICT International, Armidale, New South Wales, Australia). Ten rice plants in each plot were selected every 10 d during rice growth to measure plant height and number of tillers. Three rice plants in each plot at different growth stages were sampled to measure biomass. Rice yield was determined for each plot at harvest (30 October and 4 November in 2015 and 2016, respectively), 5 × 6 hills (holes) in each plot were selected to measure the number of panicles per unit area, number of spikelets per panicle, spikelet sterility or filled spikelet, thousand seed weight, and yield. Irrigation water use efficiency (IWUE) was calculated by dividing rice yield by irrigation water volume.

Statistical analysis

Two-way ANOVA analysis was performed to rank the factors (irrigation, SR, and the interaction between them) to determine rice growth, yield, or IWUE with SPSS19.0 software (SPSS Inc., Chicago, Illinois, USA). Fisher's least significant difference (LSD) test was used to detect the differences in rice growth and yield indices among treatments at p = 0.05.

Table 1. Nitrogen (N) fertilizer management of rice in growth period.

N fertilizer	2015	2016
	kg ha^{-1}	kg ha^{-1}
Base fertilizer	155.2 (72.0 CF + 83.2 AB) (19 June)	120.1 (60.0 CF + 60.1 AB) (28 June)
Tillering fertilizer	69.3 (U) (5 July)	97.0 (U) (13 July)
Panicle fertilizer (9 and 3 August)	58.9 U) (9 August)	104.0 (U) (3 August)
Total N	283.4	321.1

Dates in brackets are the fertilization dates, respectively.
CF: Compound fertilizer (N, P_2O_5, and K_2O contents are 16%, 12%, and 17%, respectively); AB: ammonium bicarbonate (17.1% N content); U: urea (46.2% N content).

RESULTS

Rice plant height

Plant height increased rapidly at the early and middle tillering stages (20-40 DAT) (Figure 1). It reached the highest value at the late jointing-booting stage or heading-flowering stage (approximately 80 DAT), and it was then stable until harvest. Throughout the observation period (15-125 DAT), rice plant height for CI-SR, CI-CF, FI-SR, and FI-CF fields were mainly within the following ranges: 35.6-96.6, 34.8-93.6, 35.1-97.9, and 35.8-95.4 cm in 2015, respectively, and 37.8-99.7, 36.5-95.3, 37.4-100.9, and 37.9-99.3 cm in 2016, respectively. It was clear that SR slightly promoted rice plant height compared with CF, although CI slowed down crop growth and resulted in lower plant height compared with FI. When compared with FI-CF, CI-CF decreased the maximum plant height by 1.5% and 4.4%, while CI-SR increased it by 1.7% and 0.8% in 2015 and 2016, respectively. This indicated that SR offset inhibition of rice plant growth caused by CI irrigation.

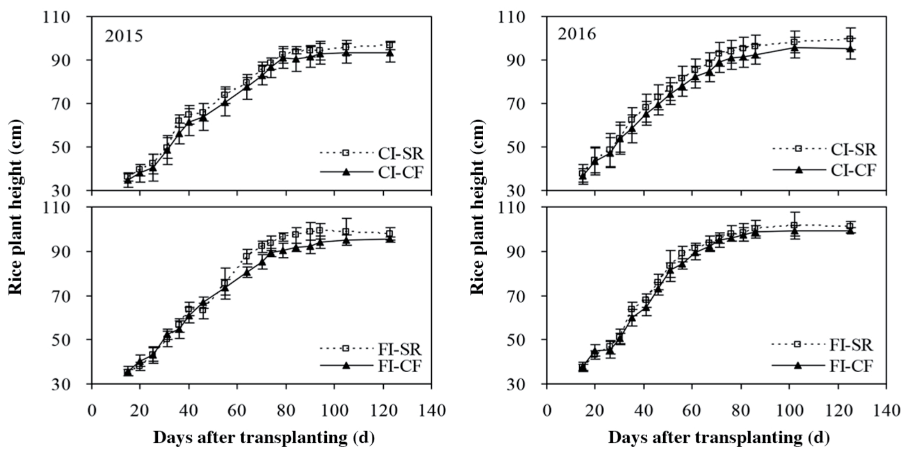
Rice tillers

The number of rice tillers was rapidly enhanced at the tillering stage and gradually decreased with the increasing number of non-effective tillers (Figure 2). The maximum number of tillers usually occurred at the late tillering or jointing stage (approximately 40 DAT). When compared with CF, SR increased the maximum number of rice tillers by 2.8% and 3.7% in 2015 and 5.1% and 5.6% in 2016; it delayed peak time by 4 and 10 d and 5 and 5 d in the two seasons, respectively. In comparison with FI-CF, CI-CF decreased the maximum number of rice tillers by 2.4% and 4.1%, while CI-SR enhanced it by 0.4% and 1.1% in 2015 and 2016, respectively. These results suggests that the fertility function of SR lagged behind the conventional fertilizer, which generally played a positive role after the middle tillering stage and led to an increase in the maximum number of rice tillers. However, for effective tillers, both CI-SR and CI-CF reduced them by 2.2% and 5.9% in 2015, and 2.1% and 5.8% in 2016, respectively, when compared with FI-CF. This indicates that SR could decrease non-effective tillers and improve effective tillers when compared with CF, although it generally caused a lower effective tiller ratio.

Biomass

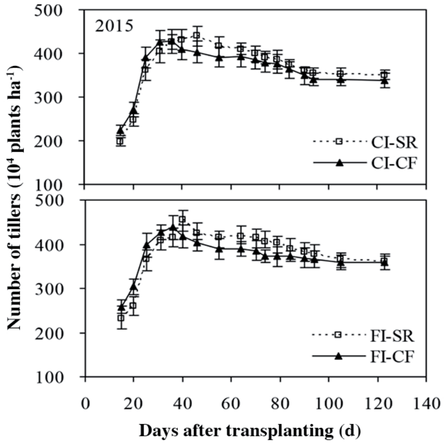
Rice biomass gradually increased over the growth period and showed a similar tendency among paddy fields with different water and fertilizer management (Figure 3). Biomass production increased more rapidly at the jointing stage (40-60 DAT) than at other stages, and reached its maximum at the milk ripening stage (approximately 90 DAT). The SR application increased biomass by 7.1% and 10.5% in 2015 and 10.0% and 11.1% in 2016, respectively, when compared

Figure 1. Variations in rice plant height during growth stages under different treatments.



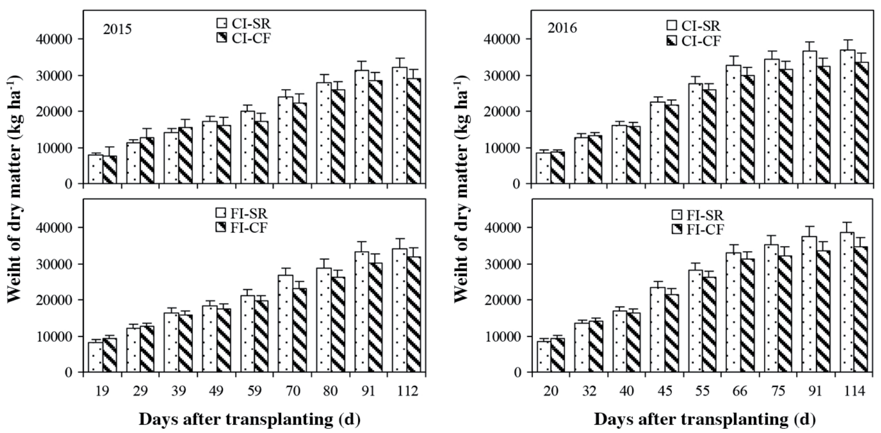
CI-CF: Controlled irrigation with conventional fertilization; CI-SR: controlled irrigation with straw returning; FI-CF: flooding irrigation with conventional fertilization; FI-SR: flooding irrigation with straw returning.

Figure 2. Variations in the number of rice tillers during growth stages under different treatments.



CI-CF: Controlled irrigation with conventional fertilization; CI-SR: controlled irrigation with straw returning; FI-CF: flooding irrigation with conventional fertilization; FI-SR: flooding irrigation with straw returning.

Figure 3. Variations in biomass during growth stages under different treatments.



CI-CF: Controlled irrigation with conventional fertilization; CI-SR: controlled irrigation with straw returning; FI-CF: flooding irrigation with conventional fertilization; FI-SR: flooding irrigation with straw returning.

with CF. Maximum biomass under CI was slightly lower and decreased on average by 5.8% and 3.6% in 2015 and 2016, respectively, when compared with FI. In comparison with FI-CF, CI-CF decreased maximum biomass by 8.6% and 3.1% while CI-SR increased it by 1.0% and 6.6% in 2015 and 2016, respectively. This reconfirmed the lag effect of SR fertilizer efficiency.

Rice yield and water use efficiency

There was nonsignificant difference in the ripening rate and thousand seed weight between paddy fields with or without SR application (Table 2). However, a significant increase was found in effective panicle for the paddy field with SR application. Rice yields in SR-applied paddy fields therefore increased by 7.9% and 7.9% and 7.1% and 8.7% and IWUE improved by 4.2% and 8.3% and 8.3% and 8.3% in 2015 and 2016, respectively. When compared with FI, rice yield from CI-irrigated paddy fields was almost the same, but IWUE significantly increased (95.3% and 96.5% and 92.9% and 97.9% in 2015 and 2016, respectively) because the irrigation water volumes under CI were 49.2% and 49.5% and 49.2% and 49.8% lower ($p < 0.05$) (Table 2).

Table 2. Rice yield and irrigation water use efficiency under different treatments.

Year	Treatment	Yield	Number of panicles ha^{-1}	Number of spikelets per spike	Ripening rate	Thousand seed weight	Irrigation volume	IWUE	Rice biomass
		kg ha^{-1}			%	g	mm	kg m^{-3}	kg ha^{-1}
2015	CI-SR	10347.2±107.2a	3744087.1±22221.4b	124.6±1.1a	83.5±3.6a	27.4±1.1a	411.3±4.7b	2.5±0.02a	31461.6±2354.7a
	CI-CF	9588.9±88.2b	3516256.5±19339.2c	122.3±1.3a	82.0±4.4a	27.1±1.2a	406.5±5.5b	2.4±0.02b	29453.8±2456.6a
	FI-SR	10422.1±105.9a	3864478.5±15501.2a	126.5±1.5a	81.6±4.5a	27.6±1.4a	809.1±9.7a	1.3±0.02c	32371.7±2628.7a
	FI-CF	9657.2±54.4b	3768579.0±16563.1b	124.1±1.0a	79.0±4.6a	27.4±1.8a	804.3±9.3a	1.2±0.01d	30338.9±2436.5a
2016	CI-SR	10408.1±104.2a	3696405.2±20571.5b	125.2±1.4a	83.1±3.7a	28.2±1.4a	401.2±5.1b	2.6±0.02a	39073.0±2672.4a
	CI-CF	9576.0±82.9b	3504520.3±19057.6c	123.4±1.2a	82.4±4.2a	27.4±1.2a	408.7±4.6b	2.3±0.03b	38692.3±2255.3a
	FI-SR	10479.0±107.3a	3856846.5±18135.2a	127.2±1.7a	81.3±4.0a	27.7±1.1a	799.2±9.6a	1.3±0.02c	26652.9±1789.0b
	FI-CF	9782.3±66.2b	3752686.2±19687.7b	124.8±1.5a	79.2±3.5a	28.1±1.3a	805.2±8.3a	1.2±0.01d	39781.7±2731.9a

CI-CF: Controlled irrigation with conventional fertilization; CI-SR: controlled irrigation with straw returning; FI-CF: flooding irrigation with conventional fertilization; FI-SR: flooding irrigation with straw returning; IWUE: Irrigation water use efficiency.
Different lowercase letters in the same column indicate significant differences ($p = 0.05$).

DISCUSSION

Straw is an important source of organic fertilizer, which usually affects the C and N cycle in the agro-ecosystem, and thus crop growth and yield (Singh, 2003; Thuy et al., 2008; Liu et al., 2014b). The present study indicated that SR slightly inhibited rice growth (plant height, number of tillers, and biomass production) during the first 20 d of the rice season, while it clearly improved after the late tillering or jointing stage (approximately 40 DAT) (Figures 1, 2, and 3). This concurs with other studies found in the literature (Sun et al., 2012; Fang, 2017). For example, Sun et al. (2012) have indicated nonsignificant differences in rice growth and biomass at the jointing stage between paddy fields with and without SR, but found differences during the ripening stage. Fang (2017) have demonstrated that rice plant height and number of tillers are lower in fields with SR than those without SR at the early growth stage; however, these clearly improved at the late growth stage. These results imply the need for a period before the straw nutrients are available for rice growth. Generally, at the initial stage after straw application, some soil available N is fixed by soil microorganisms due to high straw C/N ratio. This leads to an insufficient N supply at the seedling stage and thus inhibits rice growth (number of tillers, plant height, and biomass) (Thuy et al., 2008; Jin et al., 2013; Fu et al., 2013). However, there are more available soil nutrients with straw fermentation, which may accelerate rice growth (Singh, 2003; Han et al., 2012; Liu, 2012). In the present study, the maximum plant height, number of tillers, and biomass production at harvest improved in paddy fields with SR compared with those without SR (Figures 1, 2, and 3). This suggests that the SR promotion effect on rice growth is generally greater than its inhibition effect throughout the rice season.

Rice yields in paddy fields usually improve with SR (Xu et al., 2009; Li et al., 2009); however, there is still no consistent conclusion about the mechanism to increase yield with SR. For example, Xu et al. (2009) have found that SR enhanced rice yield by improving rice panicles ha^{-1}, ripening rate, and thousand seed weight. On the other hand, Li et al. (2009) have indicated that only improving rice panicles ha^{-1} was the key factor for increasing rice yield. In the present study, rice panicles ha^{-1} and yield significantly increased in paddy fields with SR application compared with those without SR application, while spikelets per spike, ripening rate, and thousand seed weight were not significantly different (Table 2). Two-way ANOVA also indicated that the effects of SR were significant for rice panicles ha^{-1} and yield. Thus, it can be inferred that increased rice panicles ha^{-1} may be the reason for enhanced rice yield in SR-applied paddy fields.

Previous studies have investigated the interaction effect of SR and tillage, fertilization on rice growth, and yield under FI (Mohanty et al., 2007; Pooniya and Shivay, 2012; Yadav et al., 2018; Kubar et al., 2018), but very little research has focused on the interaction effect of irrigation regimes (FI and CI) and SR on rice growth and yield (Yang et al., 2018). In the present study, two-way ANOVA analysis indicated that the effects of irrigation or SR were significant for rice growth, yield, and IWUE, while their interaction effects were nonsignificant for most of these indices (Table 3). As for rice maximum plant height and biomass at harvest, the SR effect was greater than for irrigation and was significant for rice biomass in 2016. However, the number of tillers at harvest was different and the SR effect was lower than for irrigation. Regarding yield and its components, rice spikelets per spike and yield showed a closer response to SR than irrigation, and

Table 3. Two-way ANOVA results for rice growth, yield, and irrigation water use efficiency (IWUE).

Item			2015			2016		
			I	S	I*S	I	S	I*S
Rice growth	Maximum plant height	SS	7.4	22.9	0.2	20.3	27.6	5.6
		F	0.9	2.9	0	5	6.7	1.4
		P	0.364	0.129	0.877	0.057	**0.032***	0.275
	Tillers at harvest	SS	736.9	185.5	94.5	755	190.6	96.2
		F	3.2	0.8	0.4	2.6	0.7	0.3
		P	0.113	0.398	0.542	0.143	0.438	0.578
	Biomass at harvest	SS	2.4×10^6	12.2×10^6	468.8	96.3×10^6	121.9×10^6	136.9×10^6
		F	0.4	1.9	0	14.3	18.1	20.3
		P	0.553	0.201	0.993	**0.005***	**0.003***	**0.002***
Rice yield	Number of panicles ha^{-1}	SS	4.6×10^8	3.5×10^8	0.6×10^8	1252.2×10^8	657.3×10^8	57.7×10^8
		F	301.5	227.4	37.8	333.3	175	15.4
		P	**0.000***	**0.000***	**0.000***	**0.000***	**0.000***	**0.004***
	Number of spikelets per spike	SS	10.3	16.6	0	8.7	13.2	0.3
		F	6.7	10.8	0	4.1	6.2	0.1
		P	**0.032***	**0.011***	0.946	0.079	**0.038***	0.731
	Ripening rate	SS	18	12.6	0.9	18.7	5.9	1.5
		F	0.9	0.6	0	1.3	0.4	0.1
		P	0.366	0.446	0.835	0.294	0.547	0.761
	Thousand seed weight	SS	1.3	0.2	0.1	0	0.2	0.1
		F	3.4	0.5	0.2	0	0.8	0.4
		P	0.103	0.500	0.683	0.829	0.399	0.523
	Yield	SS	1.5×10^4	174.0×10^4	32.7	5.7×10^4	175.3×10^4	1.4×10^4
		F	1.8	208.1	0	6.9	208.5	1.6
		P	0.212	**0.000***	0.952	**0.031***	**0.000***	0.237
	IWUE	SS	4.3	0	0	4.3	0.1	0
		F	13292.3	92.3	0	9600	266.7	66.7
		P	**0.000***	**0.000***	1.000	**0.000***	**0.000***	**0.000***

*Significant at $p = 0.05$.
I: Irrigation; S: straw returning; I*S: effect of irrigation and straw returning interaction; SS: sum of squares of mean deviation.

the effects of SR were significant for these two indices. As for rice panicles ha^{-1} and IWUE, both the effects of SR and irrigation were significant. As a consequence, the interactive effect of irrigation and SR was significant in both years for rice panicles ha^{-1}, but only in 2016 for rice biomass, yield, and IWUE.

Irrigation and SR are two important factors that affect rice growth and yield (Ravisankar et al., 2014; Li et al., 2016; Kaur and Mahal, 2017; Yang et al., 2018). The present study indicated that CI delayed the peak time of rice tillering and decreased plant height, number of tillers, and yield compared with FI. On the other hand, SR enhanced the maximum plant height, number of tillers, biomass production, and yield compared with those without SR application. The CI-SR combination significantly enhanced plant height, number of tillers, biomass, and yield compared with FI-CF. Since these indices were lower in CI than in FI irrigated fields (Table 2), this indicates that SR may provide some ‘buffering’ against the inhibition effect of CI on rice growth and yield. Moreover, the significantly reduced irrigation volume and improved yield in the CI-SR field resulted in a significantly higher IWUE for CI-SR; it should therefore be an effective measure for enhancing soil fertility, maintaining the rice field, and increasing IWUE.

Although there is a contradiction between improved rice yield and inhibited plant growth in the early growth stage, this likely indicates that there are still some inadequacies in the combined management of SR and chemical fertilizer for paddy fields. Thus, diverting some top-dressed chemical fertilizer to basal application may be a potential measure to mitigate SR inhibition on rice growth at the early growth stage while also meeting crop nutrient uptakes. The requirement may be more necessary for CI than FI.

CONCLUSIONS

The present study investigated rice growth and yield as affected by straw returning (SR) under water-saving irrigation (WSI). Results indicated that SR could offset the WSI-driven reduction in soil organic C content of paddy fields and was helpful for producing large rice panicles and increasing effective panicles and yield. The combined application of SR and controlled irrigation (CI) could maintain high rice yield and significantly increase irrigation water use efficiency (IWUE) of paddy fields: it should be an effective measure to achieve sustainable water and fertilizer utilization in paddy fields. Slow rice growth at the early stage, delayed tillering time, and low effective tiller ratio indicated that increasing chemical fertilizer at the basal fertilizer application stage could mitigate SR inhibition on crop growth in the early growth stage, while also meeting crop nutrient uptakes, especially for CI.

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