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Short Communication

The growth and yield of a wet-seeded rice-ratoon rice system in central China

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ABSTRACT

A ratoon rice system is one method to increase food production in areas where the period of favourable temperature for rice production is too short for double rice, and where labour scarcity constrains crop establishment. Changing from traditional transplanting to direct seeding on the puddled soil (wet seeding: WSR) further reduces the labour requirement for the rice-ratoon system. Therefore, we compared the performance of a wet-seeded rice-ratoon rice system (WSR-RR) with a traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016. The ratoon season yields (4.05–5.83 t ha^{-1}) and annual grain yields (12.4–15.7 t ha^{-1}) of WSR-RR were comparable to those of TTR-RR. In short, WSR-RR is an alternative rice planting system to TTR-RR. The higher panicle number per m2 contributed to the ratoon season yield in WSR-RR, by contrast, the ratoon season yield in TTR-RR was attributed to a higher number of spikelets per panicle. The regeneration rates of inbred rice variety (Huanghuazhan) in WSR-RR were significantly lower than those in TTR-RR, while there was no difference in the regeneration rate between WSR-RR and TTR-RR for hybrid rice variety (Tianyouhuazhan).

1. Introduction

The world is facing a potential food shortage due to the increasing population and the effect of climate change on crop productivity (Long et al., 2015). Rice is the main staple food crop for more than 3 billion people (Fageria, 2007), and it has been estimated that global rice production needs to increase by 116 million tons by 2035 to meet the rising demand for rice (Yamano et al., 2016). In addition, China will need to produce approximately 20% more rice by 2030 to meet its domestic needs (Peng et al., 2009). However, the arable land used for rice production is decreasing because of urbanization and industrialization in the major rice producing regions (Long, 2014). Future increases in rice production will have to depend on higher grain yield (Cassman et al., 2003) and more frequent harvests on the existing land (Ray and Foley, 2013).

However, yield gap analyses revealed that rice yields have been approaching their biophysical potential ceiling in recent years (Cassman et al., 2003; Lobell et al., 2009; Licker et al., 2010; Neumann et al., 2010; van Wart et al., 2013). Therefore, improving the multiple-crop index might be a promising option to increase total rice production. Two main planting patterns, i.e., double-season rice systems and ratoon rice systems, are considered as efficient systems to ensure more frequent rice harvests on the existing land.

The wide adoption of double-season rice systems in both China and elsewhere in Asia increases total rice production output per land area compared to single-season rice systems and thus contributes substantially to the global rice supply (Ray et al., 2013). In the traditional double-season rice systems, seeds are sown in a seedbed, after which seedlings are removed from the nursery and transplanted in the field in both the early and late seasons. However, the planting area of double rice cropping systems has been decreasing continuously. In China, the proportion of double rice cropping area to total rice production area has dropped from 71% in the 1970s to approximately 40% at present due to labor shortage, a low degree of mechanization, and low production efficiency of double rice cropping (Zhu et al., 2013).

Ratoon rice is the production of a second rice crop from the stubble left behind after the main crop has been harvested. The ratoon crop develops by regenerating rice tillers from nodal buds of the stubble. The development of ratoon rice is one method to increase food production because additional rice yields can be achieved with minimal agricultural inputs (Harrell et al., 2009). Ratoon rice has drawn much attention, especially in regions where the annual cumulative temperature is

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considerably more than that required for single cropping rice but is too low for double-season rice. This method has also been considered as an effective approach to improve the multiple-crop index and to increase economic benefits (Xiong et al., 2000). In addition, the grain yields in the ratoon season were reported to range from 3.0 to 3.8 t ha^{-1} (Xu et al., 2015). Furthermore, a ratoon crop yield of 9.7 t ha^{-1} was observed in Fujian province when suitable rice varieties were incorporated and the best management practices were applied (Li et al., 2009).

Compared with traditional double cropping rice systems, ratoon rice systems have the advantages of saving labor, time, seed, and nursery supplies, as well as exhibiting high utilization efficiency with respect to resources (Munda et al., 2009). Furthermore, the rice quality is better in the ratoon season than in the main season (Liu et al., 2002a). At present, the establishment method of the main season rice in ratoon rice systems is mainly seedling transplantation. However, traditional seedling transplantation is associated with high energy and labor costs (Bhushan et al., 2007). The adoption of direct seeding methods for rice crop establishment in place of transplanting has continuously increased in Asia because of increased labor costs and an improvement indirect seeding technology (Peng and Yang, 2003). Wet-seeded rice (WSR) has been proposed as an alternative rice production strategy because it reduces water consumption and labor requirements and increases system productivity and resource use efficiency (Jiang et al., 2016; Tao et al., 2016).

Considering the advantages of ratoon rice and wet-seeded rice, a wet-seeded rice-ratoon rice system might be a promising planting pattern in central China and elsewhere in Asia. Therefore, the present study, which was carried out in central China (one of the largest rice planting regions in China), aimed to determine the feasibility of a wet-seeded rice-ratoon rice system (WSR-RR) relative to a traditional transplanted rice-ratoon rice system (TTR-RR) on the basis of rice growth duration, regenerative capacity, and yield performance.

2. Materials and methods

2.1. Site description

The study was conducted in Zhougan Village (29°51′N, 115°33′E), Dajin Town, Wuxue County, Hubei Province, China, during the rice growing season of 2015 and at Jiupu Village (30°14′N, 115°25′E), Chidong Town, Qichun County, Hubei Province, China, during the rice growing season of 2016. Total nitrogen (N), available phosphorus, potassium, and organic matter in the upper 20 cm soil were 0.17%, 30.4 mg kg^{-1}, 80.7 mg kg^{-1}, and 17.7 g kg^{-1}, respectively, in 2015 and 0.22%, 7.5 mg kg^{-1}, 190 mg kg^{-1}, and 34.9 g kg^{-1}, respectively, in 2016.

2.2. Experimental design

In both 2015 and 2016, two rice planting systems were adopted: (1) wet-seeded rice-ratoon rice (WSR-RT) and (2) traditional transplanted rice-ratoon rice (TTR-RT). In 2015, an indica inbred rice cultivar was used, i.e., Huanghuazhan (HHZ), which is a mega rice variety that is usually adopted as a ratoon rice variety by farmers in central China. In 2016, an additional indica hybrid rice variety, i.e., Tianyouhuazhan (TYHZ), was used. The experiments in 2015 were completely randomized using four replicates and the two rice planting systems as treatments. The experiments in 2016 were randomly arranged using a split plot design with four replicates; the two rice planting systems were assigned to the main plots, and the cultivars were assigned to the subplots (4 m × 8 m). All plots were ploughed and puddled before seed sowing or transplanting. The wet-seeded seeds were sown manually in rows spaced 25 cm apart on April 15, 2015, and April 11, 2016. The sowing rate was 60 kg ha^{-1} for the inbred rice variety compared with 30 kg ha^{-1} for the hybrid rice variety. With respect to the traditional transplanted rice, the seed density within the seed bed was approximately 45 g m^{-2}, and the seeds were sown in the nurseries on April 15, 2015, and April 8, 2016. The transplanting dates were May 16 in 2015 and May 5 in 2016. At the time of transplanting, there were 5–6 leaves on the main tiller of the seedlings. The seedlings were transplanted into the paddy soil with a hill spacing of 25 × 13.3 cm, with 3–4 seedlings per hill for the inbred rice variety and 1–2 seedlings per hill for the hybrid rice variety.

In both years, a main season fertilizer dose of 150: 40: 100 of N: P: K kg ha^{-1} was applied equally to all treatments. All of the P, one third of the N, and half of the K were applied as a basal starter dose, while the residual N was equally split at the middle tillering stage and the panicle initiation stage, and the other 50% of the potassium was top-dressed during panicle initiation. A ratoon season fertilizer dose of 140: 38 of N: K kg ha^{-1} was applied equally to all treatments. Half of the N and all of the potassium were applied 10–15 days after flowering of the main season rice, and the other 50% of the N was applied 3 days after the main season rice was harvested. The sources of N, P, and K were urea, calcium superphosphate, and potassium chloride, respectively. Weeds, diseases, and insects were intensively controlled throughout the entire growing season in both years.

2.3. Data collection

The main crop was harvested manually, and the remaining stubble height was maintained at 40 cm. The whole plant growth durations for the two rice planting systems were recorded from the seed sowing date of the main season to the harvest date of the ratoon season. The main rice yield and ratoon yield were measured using 5-m^2 sample areas. In the mature period of the ratoon rice, a 0.5-m^2 sample was selected to calculate the yield components, regeneration rate, and productive tiller percentage. The regeneration rate was calculated as the ratio of "the number of panicles in the ratoon season" to "the number of panicles in the main season". The productive tiller percentage (%) was computed as the percentage of "the number of panicles in the ratoon season" in "max number of buds in the ratoon season".

2.4. Data analysis

Data were analyzed by analysis of variance using Statistix 9.0. The differences between treatments were separated using the least significance difference (LSD) test at the 0.05 probability level. Graphical representation of the data was performed using Sigmaplot 12.5.

3. Results

3.1. The growth durations and grain yields of the main season and ratoon season in WSR-RR and TTR-RR

No differences in the growth durations of the main season and ratoon season were observed between WSR-RR and TTR-RR in 2015. In 2016, the main season durations of HHZ and TYHZ in WSR-RR were 3 days shorter than their counterparts in TTR-RR, while the ratoon season durations of these two systems were the same (Table 1). The whole growth duration in HHZ was longer in 2015 than in 2016.

There were no significant differences in the main season yields, ratoon season yields, and annual grain yields between WSR-RR and TTR-RR in both years, except that the main season yield of HHZ in WSR-RR was higher than that in TTR-RR in 2015 (Table 2). The annual grain yields of HHZ ranged from 12.6–14.0 t ha^{-1}, which were significantly lower than those of TYHZ (over 15.0 t ha^{-1}).

3.2. Yield components of the ratoon crop in WSR-RR and TTR-RR

Among the yield components in the ratoon season, the number of panicles per m^2 in WSR-RR was higher than that in TTR-RR, while the number of spikelets per panicle was lower in WSR-RR than in TTR-RR

Table 1
Growth duration of the main season, ratoon season and the whole crop in the wet-seeded rice-ratoon rice system (WSR-RR) in comparison with the traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016.

Year	Cultivar	Planting pattern	Main season				Ratoon season			Whole crop duration (d)
			Sowing date	Heading date	Maturity date	Main crop duration (d)	Heading date	Maturity date	Ratoon crop duration (d)	
2015	HHZ	TTR-RR	4/15	7/25	8/18	124	9/19	11/1	75	199
		WSR-RR	4/15	7/22	8/18	124	9/17	11/1	75	199
2016	HHZ	TTR-RR	4/8	7/17	8/17	131	9/5	10/18	62	193
		WSR-RR	4/11	7/16	8/17	128	9/5	10/18	62	190
	TYHZ	TTR-RR	4/8	7/17	8/17	131	9/16	10/27	71	202
		WSR-RR	4/11	7/17	8/17	128	9/16	10/27	71	199

HHZ: Huanghuazhan; TYHZ: Tianyouhuazhan.

Table 2
The main season yield, ratoon yield and annual yield of Huanghuazhan (HHZ) and Tianyouhuazhan (TYHZ) in the wet-seeded rice-ratoon rice system (WSR-RR) in comparison with the traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016.

Year	Cultivar	Planting pattern	Main season yield (t ha^{-1})	Ratoon season yield (t ha^{-1})	Annual yield (t ha^{-1})
2015	HHZ	TTR-RR	8.63 b	4.87 a	13.5 a
		WSR-RR	9.50 a	4.47 a	14.0 a
2016	HHZ	TTR-RR	7.88 a	4.67 a	12.6 a
		WSR-RR	8.34 a	4.05 a	12.4 a
	TYHZ	TTR-RR	9.54 a	5.72 a	15.3 a
		WSR-RR	9.90 a	5.83 a	15.7 a

For each cultivar in a particular year, means followed by different letters within a column are significantly different from each other at the 0.05 level.

in both years (Table 3). Yield component and yield contribution were compared among panicles regenerated from different nodes in the ratoon season in the two planting systems. In general, panicles per m^2, spikelets per panicle, aboveground biomass, grain yield, and yield contribution declined as node position decreased (Table 4). The diagrams of the nodes and regenerated panicles in ratoon rice system were shown in Fig. 1. The panicles regenerated from the 2nd node from the top (D2) contributed over 60% to the total grain yield in the ratoon season, followed by approximately 30% from D3, and less than 5% from other nodes at lower positions, irrespective of cultivar, planting system, or year (Table 4). No significant differences in the yield component and yield contribution of different nodes were found between WSR-RR and TTR-RR.

3.3. Regeneration rate in the ratoon season in WSR-RR and TTR-RR

The regeneration rates of HHZ in WSR-RR were significantly lower than those in TTR-RR in both 2015 and 2016, while there was no difference in the regeneration rate between WSR-RR and TTR-RR in TYHZ (Table 5). No differences in productive tiller percentage were observed between WSR-RR and TTR-RR.

4. Discussion

Our results showed that there were no significant differences in the ratoon season yield and annual yield between WSR-RR and TTR-RR (Table 2). Liu et al. (2012a) reported that there was no difference in the ratoon season yield among direct-seeding, seedling-throwing and transplanting systems. In our study, the average ratoon season yield was 4.93 t ha^{-1} irrespective of planting system, which was markedly higher than the ratoon yield (approximately 3.00 t ha^{-1}) reported along the Gulf Coast in the USA (Harrell et al., 2009). Comparisons of yield components and yield contribution in the ratoon season between WSR-RR and TTR-RR revealed that a higher panicle number per m^2 contributed to the ratoon yield in WSR-RR. By contrast, the ratoon yield in TTR-RR was attributed to a higher number of spikelets per panicle (Tables 3 and 4).

Generally, the main factors leading to a lower and more variable grain yield under direct-seeding cultivation of rice are poor and uneven establishment, inadequate weed control and lodging susceptibility (San-Oh et al., 2004). In this study, the seeds were sown in early or the middle of April in WSR-RR to ensure maturation occurred in the ratoon season. In TTR-RR, the seeds were also sown in the seedbed on the similar date as in WSR-RR to ensure the plants were subjected to the same temperature, radiation, and other meteorological conditions. Zhang et al. (2005) reported that the most suitable sowing date for TTR-RR was in late March in Hunan province (in central China). Liu et al. (2012b) documented that the source-sink relationships of WSR-RR could be improved, and ratoon rice yield could be increased by adjusting the seeding date to an earlier period. However, it has been reported that the daily mean temperature in central China during April

Table 3
The yield components of Huanghuazhan (HHZ) and Tianyouhuazhan (TYHZ) in the ratoon season in the wet-seeded rice-ratoon rice system (WSR-RR) in comparison with the traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016.

Year	Cultivar	Planting pattern	Aboveground biomass (g m^{-2})	Panicle (No m^{-2})	Spikelets panicle^{-1}	Filled grain rate (%)	1000-grain Weight (g)	Harvest index (%)
2015	HHZ	TTR-RR	1002 a	544 a	53.9 a	70.1 a	20.2 a	41.3 a
		WSR-RR	995 a	578 a	48.0 b	69.7 a	20.2 a	39.8 a
2016	HHZ	TTR-RR	1220 b	525 b	61.0 a	68.3 a	18.3 a	33.3 a
		WSR-RR	1448 a	633 a	53.0 b	69.2 a	18.3 a	30.5 a
	TYHZ	TTR-RR	1325 a	505 b	68.9 a	71.4 a	21.7 a	40.7 a
		WSR-RR	1445 a	593 a	60.4 b	69.4 a	21.6 a	38.9 a

For each cultivar in a particular year, means followed by different letters within a column are significantly different from each other at the 0.05 level.

Table 4
The yield component and yield contribution to the total grain yield among panicles regenerated from different nodes in the ratoon season in the wet-seeded rice-ratoon rice system (WSR-RR) in comparison with the traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016.

Year	Variety	Planting patter	Position	Panicles (No m^{-2})	Spikelets $panicle^{-1}$	Filled grain rate (%)	1000-grain weight (g)	Aboveground biomass ($g\ m^{-1}$)	Yield ($t\ ha^{-1}$)	Yield contribution (%)
2015	HHZ	TTR-RR	D2	289 a	57.6 a	77.7 a	20.5 a	437 a	3.09 a	66.7 a
			D3	200 b	44.5 b	65.4 b	20.4 a	229 b	1.38 b	29.9 b
			D4	54 c	42.9 b	30.9 c	18.7 b	70 c	0.16 c	3.4 c
		WSR-RR	D2	313 a	55.5 a	80.4 a	20.6 a	471 a	3.34 a	73.2 a
			D3	194 b	41.8 b	58.8 b	20.1 ab	177 b	1.11 b	24.4 b
			D4	72 c	28.1 c	24.0 c	20.0 ab	60 c	0.11 c	2.5 c
2016	HHZ	TTR-RR	D2	291 a	71.1 a	74.4 a	17.7 bc	419 a	3.17 a	67.1 a
			D3	186 c	55.6 b	59.3 b	19.5 a	238 b	1.39 b	29.4 b
			D4	48 e	36.3 d	47.8 c	16.8 d	37 d	0.16 c	3.50 c
		WSR-RR	D2	290 a	70.2 a	76.0 a	18.0 b	413 a	3.23 a	62.9 a
			D3	252 b	46.9 c	64.0 b	18.9 a	255 b	1.66 b	32.3 b
			D4	92 d	32.1 d	42.0 c	17.0 cd	85 c	0.24 c	4.70 c
	TYHZ	TTR-RR	D2	268 a	78.3 a	78.0 a	21.7 a	503 a	4.12 a	66.0 a
			D3	203 b	61.7 b	62.9 b	21.8 a	265 b	1.99 b	31.9 b
			D4	35 c	38.3 d	41.7 c	20.2 b	34 c	0.13 c	2.1 c
		WSR-RR	D2	274 a	81.4 a	75.2 a	21.6 a	509 a	4.20 a	63.7 a
			D3	256 a	53.7 c	64.0 b	21.6 a	286 b	2.21 b	33.4 b
			D4	64 c	35.3 d	36.5 c	20.4 b	56 c	0.20 c	3.0 c

For each cultivar in a particular year, means followed by different letters within a column are significantly different from each other at the 0.05 level.
Note: D2, D3, and D4 represent the second node from the top, the third node from the top, and lower nodes below the third node of the mother stem, respectively.

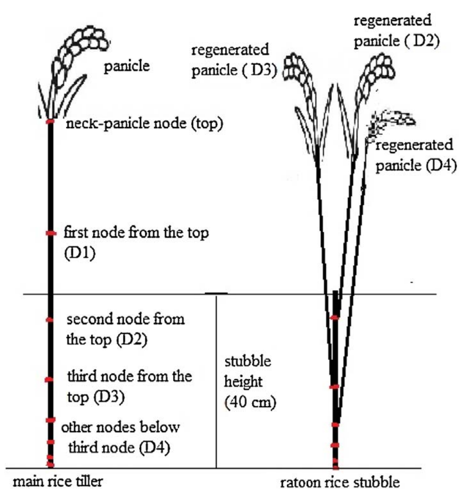

Fig. 1. The diagrams of the nodes and regenerated panicles in ratoon rice system. Every tiller (including mother tiller and other tillers) of main rice crop has several nodes. D2, D3, and D4 represent the second node from the top, third node from the top, and other nodes below the third node from main crop tillers. Regenerated rice tillers were developed from nodal buds on the remaining stubble after harvesting of main rice crop. In ratoon season, one single tiller can regenerate more than one panicles from D2, D3 or D4.

Table 5
The final regeneration rate and productive tiller percentage of Huanghuazhan (HHZ) and Tianyouhuazhan (TYHZ) in the wet-seeded rice-ratoon rice system (WSR-RR) in comparison with the traditional transplanted rice-ratoon rice system (TTR-RR) in central China in 2015 and 2016.

Year	Cultivar	Planting pattern	Final regeneration rate	Productive tiller percentage (%)
2015	HHZ	TTR-RR	1.76 a	89.9 a
		WSR-RR	1.19 b	86.7 a
2016	HHZ	TTR-RR	1.66 a	93.0 a
		WSR-RR	1.42 b	91.2 a
	TYHZ	TTR-RR	1.68 a	88.8 a
		WSR-RR	1.75 a	86.7 a

For each cultivar in a particular year, means followed by different letters within a column are significantly different from each other at the 0.05 level.

is 16.4 °C, and cold spells frequently occur in this area, which may severely hamper seed germination and the seedling growth of direct-seeded rice (Ma et al., 2011). Therefore, sustainable and effective technologies such as seed coating and seed priming treatments (Hussain et al., 2016; Wang et al., 2016) are required to improve seed germination and enhance seedling growth in WSR-RR under chilling stress. In addition, it is necessary to develop rice varieties that are cold tolerant and those with a relatively shorter growth duration (7–15 days shorter than the currently adopted ratoon rice varieties).

Lodging results in a reduction in the yield and quality of rice production, as well as a decrease in working efficiency during mechanical harvesting. Lodging is a potential disadvantage for the development of direct seeded rice (Azuma et al., 1995; Sinniah et al., 2012). This process is not only associated with variety characteristics but is also affected by agricultural operations. It was reported that the lodging risk increased as seeding and N rates increased, resulting in higher harvest costs in WSR systems (Corbin et al., 2016a). Lodging resistance can be increased through the use of suitable alternate wetting and drying irrigation practices (Yang et al., 2004), as well as the application of calcium silicon potassium fertilizer (Liu et al., 2002b) and trinexapacethyl (Corbin et al., 2016b). Choosing lodging resistant varieties and adopting targeted agricultural operations should not be ignored when developing WSR-RRs.

5. Conclusion

In central China, a ratoon season yield of over 4 $t\ ha^{-1}$can be achieved in WSR-RRs. In addition, the ratoon season yields and annual grain yields of WSR-RR are comparable to those of TTR-RR. Therefore, WSR-RR is an alternative rice planting system to TTR-RR in central China, requiring less labor. To improve seed germination and seedling growth in WSR-RR, effective pre-sowing seed treatments should be incorporated.

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