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Comparison of yield performance and rice quality between direct-seeded and hand-transplanted rice under different nitrogen rates in Eastern China

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In order to clarify whether the shift from hand-transplanting seedlings to direct seeding will bring negative effects to rice production and to find optimal nitrogen management for direct-seeded rice in Eastern China, research has been conducted in Quzhou City, in the Zhejiang Province of China in the year 2017 and 2018. One *indica* inbred rice variety, "Zhongjiazao-17" was planted by two different rice establishment methods (direct seeding and hand-transplantation), and five different nitrogen application rates were set as experimental treatments (0, 120 and 180 kg ha^{-1} in 2017 and 0, 165 and 195 kg ha^{-1} in 2018). The grain yield, economic profit, and rice quality were compared between direct-seeded rice and hand-transplanted rice under different nitrogen rates. Our results indicate that the direct-seeded rice showed no obvious disadvantages in grain yield compared to the hand-transplanted rice, but improved economic profit significantly. The highest grain yield and production profit were achieved at 180 kg N ha^{-1} in direct-seeded rice while the hand-transplanted rice achieved highest grain yield and profit at 165 kg ha^{-1}. The direct-seeded rice showed lower physical quality but higher cooking and tasting quality than the hand-transplanted rice. Increasing the nitrogen rate improved the physical quality but decreased cooking and tasting quality in both the direct-seeded rice and hand-transplanted rice. Hence, direct-seeded rice has the potential to be promoted in Eastern China, and 180 kg ha^{-1} is the optimal nitrogen rate. In addition, applying sufficient nitrogen at panicle initiation is necessary to increase the grain yield of direct-seeded rice.

Key words: Direct seeding, hand-transplantation, grain yield, nitrogen management, physical quality, cooking and tasting quality.

INTRODUCTION

China is one of the largest rice-producing countries in the world, which accounts for more than 30% of the world's rice output (Liu et al., 2019); about 65% of Chinese people consume rice as their stable food (Huang et al.,

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2014). In China, the traditional and dominant method of rice cultivation is hand-transplantation (Kumar and Ladha, 2011; Peng et al., 2009). Since the 1990s, the economic growth has been rapid in China, and many labourers have transferred from rural areas to cities, particularly in the Zhejiang Province, which is located in Yangtze River Delta economic zone in Eastern China. This phenomenon has caused the labor costs for crop production to rise significantly. In order to reduce labour costs and maintain profit margins, many farmers in China have chosen to directly-seed rice instead of using the traditional hand-transplantation method (Liu et al., 2014; Zhang et al., 2018; Ladha et al., 2009), as direct-seeded rice is considered to be a more labour- and resource-effective rice cultivation method compared to traditional hand-transplantation (Sun et al., 2015). As a result, the area of direct-seeded rice continues to increase with each passing year (Mao et al., 2018; Wang, 2015).

Apart from reduced costs of rice planting, rapid increases in the planting area of direct-seeded rice poses negative consequences to rice production systems, such as enhancing the weed-, insect-, and pest-derived damages, increasing the risk of lodging and reducing total grain yield (Akbar et al., 2011; Jat et al., 2019). Numerous studies have been conducted to compare the yield performance of direct-seeded rice and transplanted rice, but the results varied greatly among these studies (Kumar and Ladha, 2011; Farooq et al., 2011). Thus, more studies are needed to investigate the differences of yield performance and other physiological characteristics between direct-seeded rice and transplanted rice to maintain food security.

Nitrogen fertilizer is essential for vigorous rice growth and high yields, and chemical nitrogen fertilizers are extensively used to increase rice production (Cui et al., 2020). However, overuse of nitrogen fertilizer has become a very common phenomenon in rice-producing countries, especially in China (Peng et al., 2010), which has brought negative effects to grain yield and caused serious environmental problems. Numerous studies have sought to improve nitrogen management to reduce total nitrogen use and improve nitrogen use efficiency for hand-transplanted rice (Peng et al., 2010; Li et al., 2014; Chen et al., 2014). However, direct-seeded rice requires different nitrogen management because of different growth characteristics compared to transplanted rice. For example, direct-seeded rice usually has shorter crop duration than transplanted rice (Farooq et al., 2006) because hand-transplanted rice will be injured after transplanting, delaying progression (Tuong et al., 2000). Nevertheless, several studies have indicated that the method and amount of nitrogen loss is also different in direct-seeded rice compared to hand-transplanted rice (Li et al., 2015; Zhang et al., 2018). Thus, studies need to be conducted to investigate the optimal nitrogen fertilization rate and nitrogen management practices for direct-seeded rice, particularly in regions with suboptimal agricultural practices such as China.

As the living standard continues to improve and demand for high-quality rice in China increases, improving rice quality has become a new focus for rice research (Zeng et al., 2019; Peng et al., 2009). The rapid shift from traditional hand-transplanting of rice to direct seeding continues in China; more attention should be concentrated on the quality of direct-seeded rice. It has been established that nitrogen is an important factor that affects rice quality, thus a reasonable nitrogen usage amount and optimal nitrogen management could further increase rice quality as well as improve the head rice rate, reduce the percentage of grain chalkiness, and so on (Hao et al., 2007; Zhu et al, 2017; Zhou et al., 2015). However, most of these works investigated nitrogen-dependent effects in the transplanted rice system, and studies focused on the impacts of nitrogen input and management practices compared to the quality of direct-seeded rice are limited.

In this work, we conducted a series of field experiments in the early season of 2017 and 2018 in Zhejiang province of China. The objectives of this study are: 1) To compare the grain yield, yield components, and rice quality between direct-seeded rice and hand-transplanted rice under different nitrogen application rates to investigate the effects on rice production in Zhejiang Province, Eastern China; and 2) to elucidate the optimum nitrogen rate and nitrogen management for direct-seeded rice.

MATERIALS AND METHODS

Experiment site description

The experiments were conducted in a field located in the Lianhua Township, Quzhou City, Zhejiang Province, China (29°05′N, 119°01′E) in 2017 and 2018. The climate of the township is typically sub-tropical. The soil type in the area is sandy loam with 161 mg kg^{-1} available N, 19.0 mg kg^{-1} available P, 209 mg kg^{-1} available K, 45.5 g kg^{-1} organic C, and soil pH of 6.55.

Experimental design and treatment

The experiments were organized in a split-plot design with three replications. Main plots consisted of two different rice establishment methods: direct seeding (DS) or hand-transplantation (HT); sub plots consisted of three different nitrogen treatments: N0, N120, and N180 in 2017, and N0, N165, and N195 in 2018. “N0,” “N120,” “N165,” “N180,” and “N195” refer to the nitrogen application rates of 0, 120, 165, 180, and 195 kg ha^{-1}, respectively, and the detailed information is presented in Table 1. The area of each sub plot was 27 m^2 (6 m × 4.5 m) and there were approximately 1620 and 1500 seedlings in the sub plot of hand-transplanted rice in 2017 and 2018, respectively. Also, 162 g of seeds were used in the sub plot (27 m^2) of direct-seeded rice in each of the two years.

One commercial inbred *indica* rice variety, Zhongjiazao-17, was used as the experimental plant material. This rice variety has a life cycle duration (105 days) of good yield performance, and has been widely used in the early season of the Zhejiang Province. The direct-seeded rice was sown in each experiment plot on April 1, 2017 and March 30, 2018, respectively. The seedbeds were

Table 1. Seeding density and nutrient management of the three nitrogen treatments under different rice establish methods.

Year	Treatment	Density (m^{-2})	Nitrogen ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)	Phosphorus ($kg\ ha^{-1}$)
2017	N0	DS [a] 6 g seeds HT: 30 hills (20 cm×16.5 cm, 2 seedlings $hill^{-1}$)	0	90 (90-0-0)[b]	60 (60-0-0)
	N120	DS: 6 g seeds HT: 30 hills (20 cm×16.5 cm, 2 seedlings $hill^{-1}$)	120 (48-36-36)	90 (90-0-0)	60 (60-0-0)
	N180	DS: 6 g seeds HT: 30 hills (20 cm×16.5 cm, 2 seedlings $hill^{-1}$)	180 (72-54-54)	90 (90-0-0)	60 (60-0-0)
2018	N0	DS: 6 g seeds HT: 18.5 hills (30 cm×16.5 cm, 3 seedlings per $hill^{-1}$)	0	90 (90-0-0)	60 (60-0-0)
	N165	DS: 6 g seeds HT: 18.5 hills (30 cm×16.5 cm, 3 seedlings per $hill^{-1}$)	165 (66-49.5-49.5)	90 (90-0-0)	60 (60-0-0)
	N195	DS: 6 g seeds HT: 18.5 hills (30 cm×16.5 cm, 3 seedlings per $hill^{-1}$)	195 (78-58.5-58.5)	90 (90-0-0)	60 (60-0-0)

[a]DS and HT represent direct seeding, hand-transplantation, respectively.
[b]The numbers in the parentheses represents the split rates of the fertilizer application at basal, mid-tillering, panicle initiation, respectively.

prepared for the seedlings of transplanted rice, and compound fertilizer ($N:P_2O_5:K_2O$=15:15:15) was applied to the seedbed at a rate of 150 kg ha^{-1}. The hand-transplanted rice was sown on the same day as the direct-seeded rice in each of the two years and the transplanting dates were May 6th and May 3rd in 2017 and 2018, respectively.

Soils were mechanically ploughed and harrowed before sowing (for direct-seeded rice) and transplanting (for hand-transplanted rice). The basal fertilizer was applied to each experimental plot one day before sowing and transplanting. Pesticides and herbicide were used to prevent proliferation of insects, diseases, and weeds. The water management practices of direct-seeded and transplanted rice were followed as adopted by the local farmers, respectively.

Measurement and data analysis

The plant samples were harvested at maturity in each year. The sample area was 0.2 m^2 (0.4 m×0.5 m) for direct-seeded rice and 0.3 m^2 (9 plants) for hand-transplanted rice in each plot in 2017, while in 2018 the sample area was 0.25 m^2 (0.5 m×0.5 m) for direct-seeded rice and 0.3 m^2 (6 plants) for hand-transplanted rice in 2018. Each sample was separated into straw and panicles, then the panicles were threshed by hand; the spikelets were separated into filled and unfilled populations by submerging in tap water. In 2017, a subsample of 50 g of filled spikelets was taken in each plot, and in 2018, three subsamples of 30 g filled spikelets were taken in each plot, respectively. The subsample of filled spikelets and all of the unfilled spikelets were counted to calculate spikelets per panicle, grain weight, and filled grain percentage. The grain yield was determined from a 5 m^2 area in each plot and grain was adjusted to the standard moisture content of 0.14 $H_2O\ g^{-1}$ fresh weight. All plant materials were kept in an oven at 75℃ for three days and weighed to determine aerial biomass accumulation.

Rice quality was measured in 2018. The filled grain samples from each of the plots were kept for approximately 3 months under ventilated conditions for standby application. The filled grains were mechanically milled (SLJM-2009, Shanghai Shalun, China), then the milled rice was weighed and manually separated into head rice and chalky grains. The milled rice rate, head rice rate, and the percentage of grain chalkiness were calculated by the following formulas:

Milled rice rate = Milled rice weight / Filled grain weight
Head rice rate = Head rice weight / Milled rice weight
Percentage of grain chalkiness = Chalky rice number / Head rice number

A rapid visco-analyzer (RVA), RVA-TECMASTER (Perten Instruments, Sweden), was used to measure the rice starch viscosity characteristics, and the parameters of RVA spectrum include: peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown (BD), setback (SB), peak time (PT), and pasting temperature (Pat). All data were subjected to statistical testing via analysis of variance (ANOVA) using Statistic 8 software, and the means were compared by the least significant difference (LSD) test at a level of 0.05.

RESULTS

Grain yield and yield components

We found increases in grain yield as nitrogen rate increased in both the direct-seeded rice and hand-transplanted rice in 2017 (Table 2). The N180 treatment resulted in the highest grain yield, which was 6.38 t ha^{-1} for the direct-seeded rice and 5.71 t ha^{-1} for the hand-transplanted rice. The difference was not statistically significant between N120 and N180, but the grain yield of N0 was significantly lower than that of the N120 and N180 treatments. In 2018, grain yield was higher in the N195 treatment compared to the other treatments in direct-seeded rice which was 6.15 t $ha^{-1;}$ while the N165 treatment achieved the highest grain yield in hand-transplanted rice with a yield of 6.07 t ha^{-1}, but the difference between N165 and N195 was not significant. The N0 treatment also showed significantly lower grain

Table 2. Grain yield and yield components among different nitrogen treatments for direct-seeded rice and hand-transplanted rice.

Year	Methods	Treatment	Grain yield (t ha^{-1})	Spikelets number. (m^{-2})	Panicle number (m^{-2})	Spikelets per panicle	Percentage of filled grians (%)	Grain weight (mg)
2017	DS[a]	N0	2.86^{bb}	21263^{b}	248.3^{b}	85.8^{a}	79.1^{a}	25.4^{b}
		N120	5.60^{a}	26674^{ab}	273.3^{ab}	99.6^{a}	71.6^{ab}	26.9^{a}
		N180	6.38^{a}	38102^{a}	366.7^{a}	102.3^{a}	46.5^{b}	27.2^{a}
		Mean	4.95^{A}	28680^{A}	296.1^{A}	96.1^{A}	65.8^{B}	26.5^{A}
		CV(%)	37.4	30	21.1	9.2	26	3.6
	HT	N0	3.84^{b}	12230^{b}	113.3^{b}	107.0^{a}	88.9^{a}	25.5^{a}
		N120	5.67^{a}	17442^{ab}	176.7^{a}	123.2^{a}	81.0^{a}	25.7^{a}
		N180	5.71^{a}	22503^{a}	177.8^{a}	98.6^{a}	75.5^{a}	25.9^{a}
		Mean	5.07^{A}	17242^{B}	155.9^{B}	109.6^{A}	81.8^{A}	25.7^{B}
		CV(%)	21	29.5	23.6	11.4	8.2	0.8
		DS/HT	0.98	1.66	1.89	0.88	0.8	1.03
2018	DS	N0	4.29^{b}	23581^{a}	198.6^{a}	122.1^{a}	74.9^{a}	26.5^{a}
		N165	6.07^{a}	28809^{a}	229.3^{a}	126.4^{a}	71.8^{a}	26.9^{a}
		H195	6.14^{a}	28992^{a}	210.7^{a}	139.0^{a}	76.5^{a}	26.7^{a}
		Mean	5.50^{A}	27123^{A}	212.9^{A}	129.2^{A}	74.4^{A}	26.7^{A}
		CV(%)	19.1	11.3	7.3	6.8	3.2	0.75
	HT	N0	3.70^{b}	19323^{b}	143.3^{b}	134.7^{a}	76.7^{a}	27.0^{a}
		N165	6.23^{a}	27271^{ab}	184.4^{a}	140.9^{a}	70.4^{a}	26.3^{a}
		N195`	6.00^{a}	29431^{a}	210.0^{a}	147.3^{a}	70.2^{a}	25.9^{a}
		Mean	5.31^{A}	25342^{A}	179.2^{A}	141.0^{A}	72.4^{A}	26.4^{A}
		CV(%)	26.3	21	18.8	4.5	5.1	2.1
		DS/HT	1.04	1.07	1.19	0.92	1.03	1.01

[a]DS, HT, represent direct seeding, hand-transplantation, respectively.
[b]Within a column in each method, means followed by the same letters are not significantly different according to LSD (0.05).Low-case and upper-case letters indicate comparisons among three different nitrogen treatments and between two rice establish methods.

yield than the other treatments in both of the direct-seeded rice and hand-transplanted rice in 2018. The average grain yield of direct-seeded rice and the hand-transplanted rice was not significantly different in either of the two years.

Compared to the hand-transplanted rice, direct-seeded rice had a higher average number of spikelets and panicles, and increased grain weight, but a lower number of spikelets per panicle, although the difference was only significant in 2017 (Table 2). Nitrogen supplementation significantly affected spikelet number and panicle number in both the direct-seeded rice and hand-transplanted rice. The highest spikelet number and panicle number was observed in the N180 treatment in 2017 and in the N195 treatment in 2018, with the N0 treatment resulting in significantly lower spikelet number and panicle number compared to the other treatments (Table 2). The number of spikelets per panicle also increased as nitrogen supplementation rate increased but the difference was not significant among the three nitrogen treatments. No consistent difference was observed in grain weight among the different nitrogen treatments in both the direct-seeded rice and hand-transplanted rice.

Economic profit

Table 3 summarizes the estimation of total income, labor and agricultural material input, and profit among the three nitrogen treatments for direct-seeded rice and hand-transplanted rice. The total income ranged from 2537.0 to 2890.3 \$ ha^{-1} and the final profit ranged from 913.9 to 1228.5 \$ ha^{-1} in direct-seeded rice with the N180 treatment, which achieved the highest income and profit. As for hand-transplanted rice, the total income and final profit ranged from 2568.4 to 2817.8 \$ ha^{-1} and 651.9 to 827.3 \$ ha^{-1}, respectively, with the highest total income and profit being observed in the N165 treatment. The mean profit of direct-seeded rice was 1098.0 \$ ha^{-1} which was significantly higher than that of hand-transplanted rice, and the main reason was that the direct seeding of rice reduced the labor cost substantially.

Rice physical, cooking, and tasting quality

The physical qualities of rice are presented in Table 4. The milled rice rate ranged from 59.3 to 69.7% in

Table 3. Estimation of the labor costs, input, and production profit in different treatments in direct-seeded rice and hand-transplanted rice.

Year	Methods	Treatment	Grain yield (t ha^{-1})	Income[a] ($ ha^{-1})	Labor cost ($ ha^{-1})	Fertilizer + seeds cost ($ ha^{-1})	Rest input ($ ha^{-1})	Profit ($ ha^{-1})
2017	DS[b]	N120	5.6	2537	931.8	395.9	295.4	913.9
2018	DS	N165	6.07	2750.5	931.8	424.6	295.4	1098.7
2017	DS	N180	6.38	2890.3	931.8	434.6	295.4	1228.5
2018	DS	N195	6.14	2822.3	931.8	444.4	295.4	1150.7
		Mean	6.0^{Ac}	2750.0^{A}	931.8^{B}	424.8^{A}	295.4^{A}	1098.0^{A}
		CV(%)	5.4	5.6	0	4.9	0	12.1
2017	HT	N120	5.67	2568.4	1500	314.2	102.3	651.9
2018	HT	N165	6.23	2817.8	1500	343.2	102.3	827.3
2017	HT	N180	5.71	2586.8	1500	352.9	102.3	631.6
2018	HT	N195	6	2718.4	1500	362.7	102.3	753.4
		Mean	5.9^{A}	2672.8^{A}	1500.0^{A}	343.2^{B}	102.3^{B}	716.5^{B}
		CV(%)	4.5	4.4	0	6.1	0	12.8
		DS/HT	1.02	1.03	0.62	1.24	2.89	1.53

[a] The estimation of income, labor cost, fertilizer and seeds cost, rest input were based on the local early rice price, the average price for a labor a day, and the average fertilizer, seed and rest local price in 2017 and 2018. The income, costs and profit were converted in US dollar with an exchange rate of RMB against the US dollar 6.6 in 2018.
[b] DS, HT, represent direct seeding, hand-transplantation, respectively.
[c]Within a column in each method, means followed by the same letters are not significantly different according to LSD (0.05).

Table 4. Physical qualities among different nitrogen treatments in direct-seeded rice and hand-transplanted rice.

Methods	Treatment	Milled rice rate (%)	Head rice rate (%)	Percentage of grain chalkiness (%)
DS[a]	N0	59.3^{ab}	55.8^{a}	97.0^{a}
	N165	64.0^{a}	57.6^{a}	98.3^{a}
	N195	69.7^{a}	58.0^{a}	96.3^{a}
	Mean	64.4^{A}	57.1^{B}	97.2^{A}
	CV(%)	8.1	2	1
HT	N0	67.7^{a}	58.0^{b}	98.0^{a}
	N165	71.3^{a}	63.2^{ab}	98.7^{a}
	N195	67.4^{a}	71.2^{a}	98.0^{a}
	Mean	68.8^{A}	64.1^{A}	98.2^{A}
	CV(%)	3.1	10.4	0.41
	DS/HT	0.93	0.89	0.99

[a]DS, HT, represent direct seeding, hand-transplantation, respectively.
[b] Within a column in each method, means followed by the same letters are not significantly different according to LSD (0.05).Low-case and upper-case letters indicate comparisons among three different nitrogen treatments and between two rice establish methods.

direct-seeded rice and ranged from 67.4 to 71.3% in hand-transplanted rice. The treatments of N195 and N165 achieved the highest milled rice rated in direct-seeded rice and hand-transplanted rice, respectively. However, the differences were not significant among the three treatments in both the direct-seeded rice and hand-transplanted rice. The head rice rate ranged from 55.8 to 58.0% in direct-seeded rice and ranged from 58.0 to 71.2% in hand-transplanted rice. The highest head rice rate was observed in the N195 and N165 treatments in direct-seeded rice and hand-transplanted rice, respectively. The percentage of grain chalkiness was greater than 90% in all of the treatments and no significant differences were observed among different treatments for

Table 5. RVA values among different nitrogen treatments in direct-seeded rice and hand-transplanted rice.

Methods	Treat	PV (cP)[a]	TV(cP)	FV (cP)	BD(cP)	SB (cP)	PT(min)	Pat(℃)
DS[b]	N0	3698.7[ac]	2739.0[a]	4887.3[a]	959.7[a]	1188.7[a]	5.9[a]	81.2[a]
	N165	3620.0[a]	2786.0[a]	4927.5[a]	834.0[a]	1307.5[a]	6.0[a]	81.0[a]
	N195	3356.0[a]	2597.3[a]	4651.3[a]	758.6[a]	1295.3[a]	5.9[a]	81.4[a]
	Mean	3558.2[A]	2707.4[A]	4822.0[A]	850.8[A]	1263.8[B]	5.9[A]	81.2[A]
	CV(%)	5	3.6	3	11.9	5.2	1	0.2
HT	N0	3552.7[a]	2739.3[a]	4867.7[a]	813.3[a]	1315.0[b]	5.9[a]	81.7[a]
	N165	3318.3[a]	2684.3[a]	4791.3[a]	634.0[a]	1473.0[a]	6.0[a]	82.5[a]
	N195	3319.7[a]	2662.7[a]	4748.7[a]	657.0[a]	1429.0[ab]	6.0[a]	82.5[a]
	Mean	3396.9[A]	2695.4[A]	4802.6[A]	701.4[B]	1405.7[A]	6.0[A]	82.2[A]
	CV(%)	4	1.5	1.2	13.9	5.8	1	0.6
	DS/HT	1.04	1	1	1.21	0.9	0.99	0.99

both the direct-seeded rice and hand-transplanted rice. The hand-transplanted rice showed higher average milled rice rate and higher head rice rate than the direct-seeded rice, but only the difference in head rice rate was significant.

The RVA spectrum of rice in 2018 is shown in Table 5. Our results indicate that the value of PV, TV, and FV decreased with an increase in nitrogen rate while BD and SB increased with an increase in nitrogen rate. Furthermore, the value of PT and Pat exhibited little change among the different nitrogen treatments. However, most of the parameters of the rice RVA spectrum were not significantly different among the three nitrogen treatments, and the only exception was in SB of hand-transplanted rice. Nevertheless, the average value of each of the parameters of the rice RVA spectrum between direct-seeded rice and hand-transplanted rice were not significantly different with the exception of BD and SB where the BD of direct-seeded rice was significantly higher than that of hand-transplanted rice and the SB was significantly lower for direct-seeded rice than that of hand-transplanted rice.

DISCUSSION

Direct seeding is considered as a labour cost-saving method in rice production and has been accepted by an increasing number of farmers in China in recent decades. However, the growth characteristics and the yield performance of direct-seeded rice need to be evaluated in order to maintain the food security of China. In our study, we compared grain yield, yield components, economic profit and quality of direct-seeded rice and hand-transplanted rice in eastern China. The results revealed that direct-seeded rice presented no obvious disadvantage in yield performance while improving economic benefits significantly when compared to hand-transplanted rice, thereby indicating that direct-seeded rice has the potential to gain popularity and be adopted as a cost-effective method of cultivation. However, cultivation technologies need to be improved to support the growth characteristics of direct-seeded rice accordingly.

Nitrogen is one of the most important nutrients for rice (Ladha et al., 2016), and many studies have been performed to investigate the optimal nitrogen fertilization rate for direct-seeded rice, but results have varied greatly (Mahajan et al., 2011; Mahajan and Timsina, 2011; Pan et al., 2017). In our study, we found that the hand-transplanted rice achieved the highest grain yield (Table 2) and production profit (Table 3) with the N165 treatment in the year 2018, and the yield components were also at a high level with this treatment. Thus, we propose 165 kg N ha^{-1} as a reasonable nitrogen rate for hand-transplanted rice in eastern China. In contrast from hand-transplanted rice, the direct-seeded rice reached the highest grain yield with the N180 treatment in 2017, and the rice yield components and the production profit of rice were also higher than the other treatments. Therefore, we think the nitrogen rate for the direct-seeded rice in eastern China should be higher than for that of hand-transplanted rice; perhaps 180 kg N ha^{-1} is suitable for the direct-seeded rice.

The increase in rice yield was always associated with improvement in yield components, especially sink size (Wu et al., 2013; Zhang et al., 2013; Shi et al., 2017). The sink size is determined by the panicle number, the spikelets per panicle, and the grain weight at physiological maturity (San-oh et al., 2004; Huang et al., 2019). In our study, we found that the grain yield was positively correlated with spikelet number per m^2, panicle number per m^2, and spikelets per panicles in both the direct-seeded rice and hand-transplanted rice (Figure 1), which was consistent with the previously mentioned studies. However, the grain yield of hand-transplanted rice showed a tighter relationship with panicle number per m^2 than the direct-seeded rice did, while hand-transplanted rice showed a less robust relationship between spikelets per panicle than the direct-seeded rice did. These results

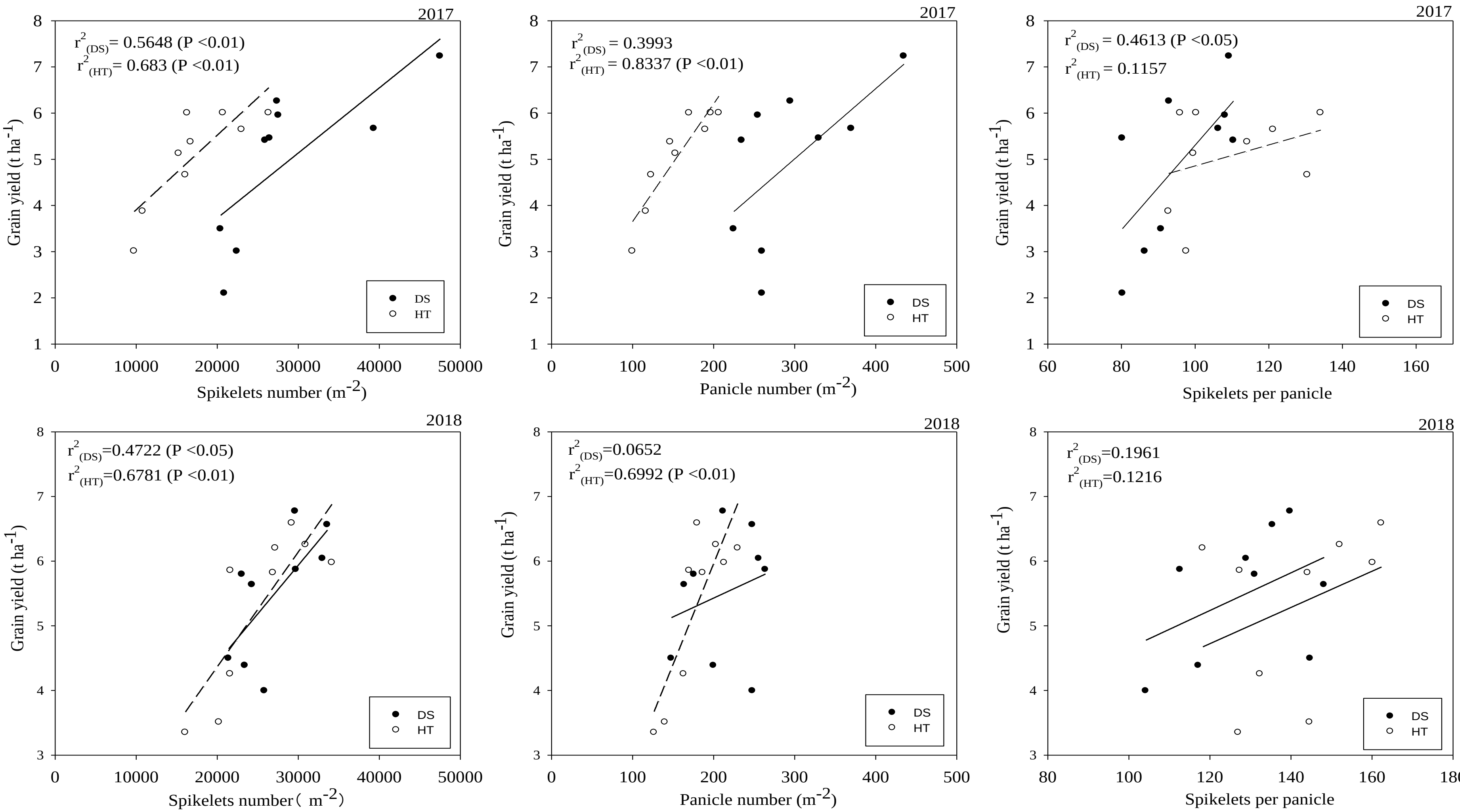

Figure 1. The relationship of grain yield with spikelet number per m^2, panicle number and spikelets per panicle in direct-seeded rice and hand-transplanted rice. DS, HT represent direct-seeding, hand-transplantation, respectively.

indicate that increasing panicle size is the most effective way to enhance yield performance of direct-seeded rice and that panicle number is important for improving the grain yield of hand-transplanted rice. Numerous studies indicated that sink size is closely related to nitrogen uptake in rice (Tadahiko, 2011; Fu et al., 2019; Chu et al., 2019). As our results indicated that grain yield was enhanced more effectively by increasing the panicle number in hand-transplanted rice, and by increasing spikelets per panicle in direct-seeded rice, it follows that more nitrogen should be applied at the tillering stage to increase the panicle number for hand-transplanted rice because the panicle number is positively related with the tiller number (Ao et al., 2010). Likewise, providing sufficient nitrogen at the panicle initiation stage perhaps is important to increase the spikelets number per panicle and grain yield in direct-seeded rice.

The physical quality of direct-seeded rice and hand-transplanted rice has been compared in our research, and we found that the average milled rice rate and the head rice rate of direct-seeded rice was lower than that of hand-transplanted rice. This result indicates that promoting direct-seeded rice cultivation will perhaps bring some risks that might decrease rice physical quality. Many studies found that increasing nitrogen use amounts could improve rice physical quality (Wei et al., 2018, Zhu et al., 2017). In our research, we found that compared to the treatment of N0, the N165 and N195 treatments showed higher milled rice rates and head rice rates in both the direct-seeded rice and hand-transplanted rice although most differences were not significant, which was consistent with the conclusions of the previous studies (Table 4). However, the milled rice rate and head rice rate was highest with the N195 treatment in direct-seeded rice, while the hand-transplanted rice achieved the highest milled rice rate with the N165 treatment, so perhaps the direct-seeded rice should have more nitrogen applied to improve rice physical quality.

Rice RVA values have been used to reflect the rice cooking and tasting quality (Tong et al., 2014), and it has been observed that rice with high cooking and tasting quality has high BD values and lower SB values (Tang et al., 2019). From the results of our study, we found that the direct-seeded rice showed higher cooking and tasting quality than the hand-transplanted rice because the average value of BD in direct-seeded rice was higher than that of the hand-transplanted rice and the average SB value was lower in the direct-seeded rice compared to the hand-transplanted rice (Table 5). Nevertheless, we found that nitrogen will bring negative effects to rice cooking and tasting quality and is likely a result of the decrease in BD and increase in SB relative to the N0 treatment in both the direct-seeded rice and hand-transplanted rice, although most of the differences were not significant.

Conclusion

Generally speaking, our research found that the direct-seeded rice has the potential to be promoted as an effective form of rice cultivation in eastern China because it showed no obvious disadvantages in yield performance when compared to hand-transplanted rice while improving economic profit margins and rice tasting quality significantly. We determined the optimal nitrogen application rate for direct-seeded rice to be 180 kg N ha^{-1}, which was higher than that of hand-transplanted rice. Additionally, the grain yield of direct-seeded rice had a more positive correlation with the number of spikelets per panicle than hand-transplanted rice. Therefore, we suggest that more nitrogen should be applied at panicle initiation to promote panicle formation in direct-seeded rice. Finally, we found that although increasing the nitrogen rate could increase rice physical quality, the tasting quality was reduced concurrently, and further studies are needed to understand how to resolve this issue.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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