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Effects of Mixed Planting on Machine Transplanting Adaptability and Grain Yield of Hybrid Rice

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Abstract: Because the current hybrid rice machine transplanting sowing quantity is too large and the high rate of missing hills or poor seedling quality during mechanical transplanting, the mechanized planting of hybrid rice is limited, which results in significant hindrance of large-scale planting of hybrid rice in China. In this study, a mixed sowing technology (replacement of a portion of hybrid rice seeds with conventional rice seeds) in seedling cultivation was adopted to determine the appropriate variety combinations and conventional rice sowing quantity using a variety combination experiment and sowing quantity experiments, respectively. The results of the variety combination experiment showed that combinations of Changyou 4 mixed with Nanjing 5055, and Yuanliangyou mixed with Yangdao 6 could reduce the sowing quantity of hybrid rice, improve the quality of machine transplanting, and not reduce the grain yield. The results of the conventional rice sowing quantity experiment showed that with the increase in conventional rice sowing quantity, the seedling quality, spikelet per panicle, and filled kernel percentage decreased, and the mechanical transplanting quality improved. Compared with pure sowing hybrid rice, the grain yield was not significantly different in the japonica rice treatment when the sowing quantity of Nanjing 5055 was more than 75 g/tray and Yangdao 6 was more than 60 g/tray. With the increase in conventional rice sowing quantity, the missing hill rate decreased significantly and the seedling density increased significantly, so that the panicle number was also improved, which might have compensated the reduction in seedling quality, spikelet per panicle, and filled kernel percentage. As a whole, 90 g Nanjing 5055 seeds mixed with 30 g Changyou 4 seeds per tray and 75 g Yangdao 6 seeds mixed with 30 g Yuanliangyou seeds per tray were suitable sowing quantities for mixed planting that could ensure strong seedlings and better mechanical transplanting quality, while reducing the cost (reduce the sowing quantity of hybrid rice and conventional rice) without reducing the grain yield.

Keywords: hybrid rice; mixed plant; seedling quantity; machine transplanting quality

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1. Introduction

At present, the global food demand is increasing, with the total demand expected to increase by 35% to 56% by 2050. Rice is one of the two most important cereals in the world [1]. With the growing global population and the demand for food consumption, researchers have been working to increase the potential yield of rice [2]. Studies have shown that global rice production must increase by 1% per year in order to meet food needs when considering population growth and economic development [3]. Therefore, the cultivation of rice varieties with a high yield potential is an important method to address the challenges of increased demand for food. The cultivation of hybrid rice varieties is one of the main methods to address this requirement because hybrid rice has obvious yield advantages over conventional rice and can effectively increase the yield of rice [4,5].

China ranks first in the global rice planting area and unit yield and is also a pioneer in the application of hybrid rice technology, which has resulted in important contributions to world food security [6,7]. In recent years, with the development of the economy, a large labor force has been transferred from rural to urban areas in China; this has resulted in the input of the labor force in rice production being greatly reduced and the cost of manual transplanting being increased, which has promoted the rapid transformation of the rice planting mode to mechanization [8]. The use of rice mechanical transplanting instead of labor-intensive hand transplanting can significantly reduce the labor force.

Studies have shown that hybrid rice needs to be planted in a low population density environment to allow for full heterosis and to obtain maximum yields [9]. However, it is difficult to carry out mechanical transplanting for hybrid rice at a low density due to the high missing hill rate during mechanical transplanting, which can eventually lead to yield loss [10–12]. Although the increase in the sowing quantity of hybrid rice increased the seeding density in the nursery tray and reduced the missing hill rate during mechanical transplanting, it also aggravated competition among seedlings, led to a reduction in seedling quality, and hindered hybrid rice heterosis [13,14]. Therefore, an increase in the sowing quantity of hybrid rice alone cannot effectively increase the rice yield; in contrast, the cost of rice production is increased due to the high price of hybrid rice seeds [15]. The above are the reasons most farmers choose to plant conventional rice or continue to use hand transplanting to plant hybrid rice; these continued practices result in the planting area of hybrid rice in China declining year by year [16,17]. Therefore, it is of great significance to improve the mechanical transplanting adaptability of hybrid rice while ensuring its seedling quality to promote the planting of hybrid rice in China [18–20].

Rice mixed cultivation is a seedling cultivation method in which different species of rice seeds are mixed and then sown [21]. Many studies have shown that rice mixed cultivation can effectively improve the stress resistance of populations of rice and bring about yield increase effects [22,23]. However, the method of mixed sowing of hybrid rice and conventional rice has not yet been studied. Therefore, we mixed hybrid rice seeds with conventional rice seeds in a fixed proportion for seedling cultivation and transplantation, in order to ensure the appropriate sowing quantity in the seedling tray and reduce the use of hybrid rice seeds. Finally, the missing hill rate of hybrid rice machine transplanting was reduced, and the adaptability of hybrid rice machine transplanting was improved. These properties were of great significance to realize the mechanization of hybrid rice in a large area, accelerate the reform of hybrid rice breeding and cultivation, expand the planting area of hybrid rice in China, and promote the development of hybrid rice.

The present study had two main objectives: (1) to determine the appropriate variety combinations and hybrid rice sowing quantity, and (2) to explore the appropriate sowing quantity of conventional rice on the basis of determining the sowing quantity of hybrid rice.

2. Materials and Methods

2.1. Experimental Site

The study site was a field located at the Shatou Experimental Base of the College of Agronomy of Yangzhou University (32°27 N, 119°34 E), Shatou Town, Yangzhou City, Jiangsu Province, China, in 2020–2022. The soil type was mucky soil with an initial pH of 7.79, organic matter of 21.01 g·kg^{-1}, total nitrogen of 1.45 g·kg^{-1}, alkaline hydrolysis nitrogen of 157.29 mg·kg^{-1}, available phosphorus of 18.77 mg·kg^{-1}, and rapidly available potassium of 138.65 g·kg^{-1} in. This study site is located in the central part of Jiangsu Province, which belongs to a subtropical temperate climate, and the preceding crop is wheat.

2.2. Experimental Design and Management

In this study, a variety matching experiment was designed in 2020–2021 to determine the best matching variety and the best sowing quantity of hybrid rice. The experiments of different conventional rice sowing quantity were conducted in 2021–2022 to further determine the optimal sowing quantity of conventional rice.

Variety matching experiment: The main japonica rice varieties, including hybrid japonica rice Changyoujing 6, Jiayouzhongke 1, Changyou 4 and conventional japonica rice Nanjing 5055, and main indica rice varieties, including hybrid indica rice Dexiang 4013, Yuanliangyou, Yixiangyou 2115, and conventional indica rice Yangdao 6, in China, were selected for mixing. Their plant height, whole growth period, and germination percentage are shown in Table 1.

Table 1. Plant height, growth period duration, and seed germination percentage of different varieties (variety matching experiment).

Subspecies	Varieties	Plant Height (cm)	Whole Growth Period (d)	Germination Percentage (%)
Japonica rice	Changyoujing 6	123	166	92.65
	Jiayouzhongke 1	112.3	147	91.45
	Changyou 4	109.5	163	91.62
	Nanjing 5055	106.5	160	90.05
Indica rice	Dexiang 4103	129.7	132	91.74
	Yuanliangyou	111.6	138	91.24
	Yixiangyou 2115	120.5	156	92.48
	Yangdao 6	115.0	145	92.83

The variety matching experiment carried out two years of research in 2020 and 2021. The seedling cultivation was conducted on 25 May. The hybrid japonica rice Changyoujing 6, Jiayouzhongke 1, and Changyou 4 were mixed with the conventional japonica rice Nanjing 5055, separately, and Dexiang 4013, Yuanliangyou, and Yixiangyou 2115 were mixed with the conventional indica rice Yangdao 6. The experiment was included six combinations (Changyoujing 6 mixed with Nanjing 5055, Jiayouzhongke 1 mixed with Nanjing 5055, Changyou 4 mixed with Nanjing 5055, Dexiang 4013 mixed with Yangdao 6, Yuanliangyou mixed with Yangdao 6, and Yixiangyou 2115 mixed with Yangdao 6) and two proportions (the sowing quantities of hybrid rice and conventional rice were 60 g mixed with 60 g and 30 g mixed with 90 g per tray, respectively, as shown in Table 2). The total seedling quantity per tray was 120 g (that is, 36 kg per hectare, consistent with the conventional mechanical transplanting seedling quantity of conventional rice). Commercial seedling raising substrate and a 30 × 60 cm nursery tray were used for seedling cultivation on 25 May and transplanting was carried out using an Iseki PZ60 speed transplanter ((PG63DVRF + Long mat (PG6, 63) SET, Iseki Co., Ltd., Matsuyama, Ehime prefecture, Iyo, Japan) on 13 June. Rice seedlings of each treatment were transplanted at a hill spacing of 30 × 16 cm. The plot for the field experiments was 28.8 m^2 (3.6 × 8 m) with three replications. The rice grain yield and yield components were measured at maturity.

Sowing quantity of conventional rice experiment: The main japonica rice varieties, including hybrid japonica rice Changyou 4 and conventional japonica rice Nanjing 5055, and main indica rice varieties, including hybrid indica rice Yuanliangyou and conventional indica rice Yangdao 6, according to the results of the variety matching experiment were selected and are presented in Table 3.

The variety matching experiment carried out two years of research in 2021 and 2022. The seedling cultivation experiment was conducted on 19 May. The experiment was divided into a japonica rice mixed treatment and an indica rice mixed treatment. Changyou 4 seeds were mixed and matched with Nanjing 5055 seeds, and Yuanliangyou seeds were mixed and matched with Yangdao 6 seeds. Japonica rice and indica rice were divided into seven groups of treatment combinations, among which one group of pure hybrid rice seeds was used as a control. In the mixed sowing treatment, the seeding rate of the hybrid rice was 30 g per tray. Then, the seeding rate of the conventional rice mixed with 45 g, 60 g, 75 g, 90 g, 105 g, and 120 g was gradually increased (Table 4). Changyou 4 and Yuanliangyou seedlings were sown 75 g per tray (that is, 22.5 kg per ha, which was consistent with the amount of mechanical transplanting in production at present), expressed by MJ-CK and MI-CK, respectively. A commercial seedling raising substrate and a 30 × 60 cm nursery tray were used for seedling cultivation. Seedling cultivation was repeated with 10 trays per treatment. Mechanical transplanting was the same as for the variety matching experiment. The plots of both experiments were fertilized with total rates of 270 kg N ha^{-1}, 180 kg P ha^{-1}, and 135 kg K ha^{-1}. As a basal dressing, 81 kg N ha^{-1}, 180 kg P ha^{-1}, and 135 kg K ha^{-1} were applied at 1 day before transplanting; 81 kg N ha^{-1}, 54 kg N ha^{-1}, and 54 kg N ha^{-1} were applied as a topdressing at 1 week after transplanting, panicle initiation, and the penultimate-leaf appearance stage, respectively. The irrigation regime adopted in the field experiment followed alternate wetting and drying cycles [24]. Chemical controls of pests, disease, and weed were performed following local practices.

Table 2. The sowing quantity of different varieties in different treatments during seedling cultivation (variety matching experiment).

Varieties	Treatment	Hybrid Rice (g/tray)	Conventional Rice (g/tray)	Total Sowing Amount of Rice (g/tray)
Changyoujing 6 mixed with Nanjing 5055	CYJ 6-CK	75	0	75
	CYJ 6-1	60	60	120
	CYJ 6-2	30	90	120
Jiayouzhongke 1 mixed with Nanjing 5055	JYZK 1-CK	75	0	75
	JYZK 1-1	60	60	120
	JYZK 1-2	30	90	120
Changyou 4 mixed with Nanjing 5055	CY 4-CK	75	0	75
	CY 4-1	60	60	120
	CY 4-2	30	90	120
Dexiang 4013 mixed with Yangdao 6	DX 4013-CK	75	0	75
	DX 4013-1	60	60	120
	DX 4013-2	30	90	120
Yuanliangyou mixed with Yangdao 6	YLY-CK	75	0	75
	YLY-1	60	60	120
	YLY-2	30	90	120
Yixiangyou 2115 mixed with Yangdao 6	YXY 2115-CK	75	0	75
	YXY 2115-1	60	60	120
	YXY 2115-2	30	90	120

Table 3. Plant height, growth period duration, 1000-grain weight, and seed germination percentage of different varieties.

Subspecies	Varieties	Plant Height (cm)	Whole Growth Period (d)	1000-Grin Weight (g)	Germination Percentage (%)
Japonica rice	Changyou 4	109.5	163	29.65	91.62
	Nanjing 5055	106.5	160	26.03	90.05
Indica rice	Yuanliangyou	111.6	138	25.02	91.24
	Yangdao 6	115.0	145	32.87	92.83

2.3. Data Collection

When the seedlings had three leaves and one heart (19 days after sowing), four trays of seedlings were randomly selected from each treatment to cut 8 × 8 cm seedlings, and the roots were rinsed with clean water after being brought back to the laboratory to determine the seedling emergence rate and seedling density:

Seedling emergence rate = seedling number/seed number × 100%

Seedling density = seedling number/sampling area.

Table 4. The sowing quantity of different varieties in different treatments during seedling cultivation.

Varieties	Treatment	Hybrid Rice (g/tray)	Conventional Rice (g/tray)	Total Sowing Amount of Rice (g/tray)	Hybrid Rice (kg/ha)	Conventional Rice (kg/ha)
Changyou 4 mixed with Nanjing 5055	MJ-1	30	45	75	9	13.5
	MJ-2	30	60	90	9	18
	MJ-3	30	75	105	9	22.5
	MJ-4	30	90	120	9	27
	MJ-5	30	105	135	9	31.5
	MJ-6	30	120	150	9	36
	MJ-CK	75	0	75	22.5	0
Yuanliangyou mixed with Yangdao 6	MI-1	30	45	75	9	13.5
	MI-2	30	60	90	9	18
	MI-3	30	75	105	9	22.5
	MI-4	30	90	120	9	27
	MI-5	30	105	135	9	31.5
	MI-6	30	120	150	9	36
	MI-CK	75	0	75	22.5	0

Thirty seedlings were randomly selected from each treatment from the retrieved seedlings to measure plant height, leaf age, seedling stem width, the length of the longest roots, and white root number per plant, and the SPAD of each seedling was determined by the middle of the uppermost fully expanded leaf of each seedling using a chlorophyll meter (SPAD-502, Minolta, Osaka, Japan).

One hundred seedlings were randomly selected from each treatment from the retrieved seedlings, and each seedling was divided into two portions (shoot and root). The length of each shoot was recorded, and all of the seedling samples were placed in an oven at 105 °C for 30 min with subsequent oven-drying at 80 °C until constant weight to determine the dry weight of the shoots and roots. The weight−height ratio was calculated as follows:

Weight−height ratio = shoot dry weight/plant height

Ten seedlings were selected from each treatment; after pruning their roots down to 0 cm, they were placed in a plastic box and cultured in distilled water. After seven days, the total length of newly growing roots for each seedling was recorded as the rooting ability in water. For the determination of the root twisting power, one side of the seedling tray was fixed, and the other side was nipped in large splints. An electronic dynamometer was used to pull seedlings in the tray horizontally until the seedlings were torn away, and the maximum tension was determined as the root twisting power. Three trays of seedlings were used for each treatment.

Three days after transplanting, a six-line monitoring spot (one operational width of the transplanter and six lines) was designed in each plot; in each line, 100 consecutive hills were examined. The number of missing hills, floating seedlings, damaged seedlings, overturned seedlings, entwined seedlings, and seedlings per hill per line were recorded to assess the mechanical transplanting quality [10].

At maturity, the panicle number per m^2 was determined using the five-point sampling method. Panicles were hand-threshed and the filled spikelets were separated from unfilled spikelets by submerging them in tap water. Three subsamples of 30 g of filled spikelets and all unfilled spikelets were taken to count the number of spikelets. All unfilled spikelets were also air-dried and counted to determine the number of unfilled spikelets. Grain yield was determined from five points (each point is 1 square meter) in each plot. The standard moisture content of japonica rice was adjusted to 14%, and that of indica rice was adjusted to 12.5% and then the grain yield was calculated.

2.4. Statistical Analysis

One-way analysis of variance (ANOVA) was conducted to determine the effects ($p < 0.05$) of different variety combinations on the grain yield and yield components in the variety matching experiment. One-way analysis of variance (ANOVA) was also conducted to assess the effects ($p < 0.05$) of different conventional rice sowing quantities on the seedling quality, mechanical transplanting quality, and yield component in the sowing quantity of conventional rice experiment. Two-way ANOVA was conducted to determine the effects of year, mixed planting treatment, and interactions between the two on the yield components of four treatments (CY 4-CK, CY 4-2, YLY-CK, and YLY-2 in the variety matching experiment; MJ-CK, MJ-4, MI-CK, and MI-4 in sowing quantity of conventional rice experiment). The LSD test was performed to identify significant differences in the means at a significance level of 5% using SPSS 20 software (SPSS, Chicago, IL, USA). Origin 2021 (Analytical software Northampton, Hampton., MA, USA) was used to analyze the correlation of different conventional rice sowing quantities with the seedling population emergence rate, seeding per square centimeter, root entwining force, and leaf SPAD in the sowing quantity of conventional rice experiment. There was no effect of years (years factor) on the two experiments' research results, so they were presented as averages over year, such as the variety matching experiment in 2020–2021 or sowing quantity of conventional rice experiment in 2021–2022.

3. Results

3.1. Effect of Different Varieties Combination on the Grain Yield and Yield Components

In the mixed treatment of Changyoujing 6, Jiayouzhongke 1, Dexiang 4013, and Yixiangyou 2115, their grain yields had no significant difference between different mixed proportions, but were significantly lower than their respective conventional control treatments (Table 5). Yield components analysis showed that although the effective spikelet per panicle of mixed treatment was significantly increased compared with conventional control treatment, the increase was not enough to make up for the shortage of spikelet per panicle. For example, the effective spikelet per panicle of CYJ 6-1 and CYJ 6-2 only increased by 11.57% and 10.15% compared with CYJ 6-CK, respectively. The grain yield of CY4-1 and CY4-2 had no significant difference compared with CY4-CK. Although the spikelets per panicle of CY4-1 and CY4-2 were significantly lower than that of CY4-CK, their filled kernel percentages were significantly increased by 3.42% and 3.23% compared with CY4-CK, respectively, and their 1000-grain weight was significantly increased by 9.52% compared with CY4-CK, which was the main reason their grain yield was not significantly different from that of the control treatment. There was no significant difference in the grain yield of YLY-CK between YLY-1 and YLY-2; although the spikelet per panicle and 1000-grain weight of YLY-1 and YLY-2 were significantly lower than that of YLY-CK, their effective spikelet per panicle significantly increased by 29.84% and 30.14%, respectively, compared with that of YLY-CK, which made up for the shortage of spikelet per panicle and 1000-grain weight.

3.2. Effect of Different Conventional Rice Sowing Quantities on Seedling Population Emergence Rate and Seedling per Square Centimeter

In the mixed treatment, the seedling emergence rate of japonica rice and indica rice decreased with increasing the conventional rice sowing quantity, and the decreasing range increased with increasing the conventional rice sowing quantity in the mixed treatment of japonica rice (Figure 1). In terms of conventional controls, the seedling emergence rate of Changyou 4 was 84.89% when it was sown at 75 g/tray (MJ-CK) alone. When the conventional rice sowing quantities were 45 g (MJ-1) and 60 g (MJ-2) Nanjing 5055, compared with MJ-CK, the seedling population emergence rate increased by 3.48% and 1.97%, respectively. When conventional rice sowing quantities were 75 g (MJ-3), 90 g (MJ-4), 105 g (MJ-5), and 120 g (MJ-6), compared with MJ-CK, the seedling population emergence rate decreased by 5.52%, 9.37%, 13.24%, and 15.02%, respectively. The seedling population emergence rate of Yuanliangyou was 82.37% when it was 75 g/tray (MI-CK) alone. Compared with MI-CK, when the conventional rice sowing quantity was 45 g (MI-1) and 60 g (MI-2) of Yangdao 6, the seedling population emergence rate increased by 3.3% and 0.69%, respectively, while the seedling population emergence rate of 75 g (MI-3), 90 g (MI-4), 105 g (MI-5), and 120 g (MI-6) decreased by 4.68%, 9.14%, 13.0%, and 17.5%, respectively.

Table 5. Effect of different variety combinations on the grain yield and yield components.

Mixed Varieties	Treatment	Hybrid Rice + Conventional Rice (g/tray)	Panicle Number m^{-2}	Spikelet per Panicle	Filled Kernel Percentage (%)	1000-Grain Weight (g)	Grain Yield (t ha^{-1})
Changyoujing 6	CYJ 6-CK	75 + 0	262.35 ± 3.68 b	146.67 ± 4.91 a	94.33 ± 0.49 a	24.63 ± 0.09 c	8.86 ± 0.11 a
mixed with	CYJ 6-1	60 + 60	292.71 ± 2.20 a	129.67 ± 4.41 b	89.33 ± 0.66 b	25.53 ± 0.15 b	8.41 ± 0.14 b
Nanjing 5055	CYJ 6-2	30 + 90	288.97 ± 2.80 a	125.33 ± 2.03 b	89.40 ± 1.13 b	25.97 ± 0.09 a	8.32 ± 0.08 b
Jiayouzhongke 1	JYZK 1-CK	75 + 0	202.78 ± 4.34 b	232.33 ± 3.28 a	87.73 ± 0.35 a	28.33 ± 0.12 a	11.50 ± 0.17 a
mixed with	JYZK 1-1	60 + 60	262.40 ± 2.91 a	157.67 ± 2.19 b	86.93 ± 0.93 a	27.77 ± 0.09 b	9.83 ± 0.16 b
Nanjing 5055	JYZK 1-2	30 + 90	254.90 ± 1.15 a	156.33 ± 3.28 b	87.43 ± 0.98 a	27.90 ± 0.12 b	9.63 ± 0.28 b
Changyou 4	CY 4-CK	75 + 0	286.50 ± 7.75 a	161.67 ± 4.06 a	82.70 ± 0.21 b	24.17 ± 0.09 b	9.17 ± 0.51 a
mixed with	CY 4-1	60 + 60	319.17 ± 16.53 a	132.00 ± 3.06 b	85.63 ± 0.03 a	26.47 ± 0.33 a	9.50 ± 0.62 a
Nanjing 5055	CY 4-2	30 + 90	323.46 ± 7.75 a	130.00 ± 3.61 b	85.37 ± 0.35 a	26.47 ± 0.34 a	9.45 ± 0.25 a
Dexiang 4013	DX 4013-CK	75 + 0	187.14 ± 5.44 b	202.68 ± 2.71 a	85.35 ± 0.36 a	30.31 ± 0.12 a	9.71 ± 0.07 a
mixed with	DX 4013-1	60 + 60	245.83 ± 1.76 a	164.04 ± 4.63 b	84.18 ± 0.47 a	27.58 ± 0.10 b	9.32 ± 0.10 b
Yangdao 6	DX 4013-2	30 + 90	240.06 ± 5.02 a	166.24 ± 4.43 b	83.91 ± 0.38 a	27.67 ± 0.07 b	9.23 ± 0.13 b
Yuanliangyou	YLY-CK	75 + 0	197.74 ± 4.04 b	205.00 ± 8.74 a	88.81 ± 1.52 a	26.82 ± 0.13 a	9.62 ± 0.25 a
mixed with	YLY-1	60 + 60	256.75 ± 3.63 a	174.33 ± 3.93 b	85.10 ± 1.70 a	25.85 ± 0.07 b	9.71 ± 0.42 a
Yangdao 6	YLY-2	30 + 90	257.33 ± 15.14 a	171.00 ± 5.20 b	85.95 ± 2.54 a	25.82 ± 0.08 b	9.72 ± 0.45 a
Yixiangyou 2115	YXY 2115-CK	75 + 0	210.09 ± 2.34 b	168.05 ± 3.50 a	82.98 ± 0.94 a	30.45 ± 0.06 a	8.71 ± 0.10 a
mixed with	YXY 2115-1	60 + 60	248.71 ± 8.06 a	148.28 ± 2.10 b	80.60 ± 1.07 a	27.56 ± 0.17 b	8.14 ± 0.15 b
Yangdao 6	YXY 2115-2	30 + 90	248.48 ± 3.72 a	146.07 ± 3.77 b	80.98 ± 1.20 a	27.44 ± 0.23 b	7.97 ± 0.18 b

For a given subspecies, values (mean ± SD) followed by different letters are significantly different at $p < 0.05$.

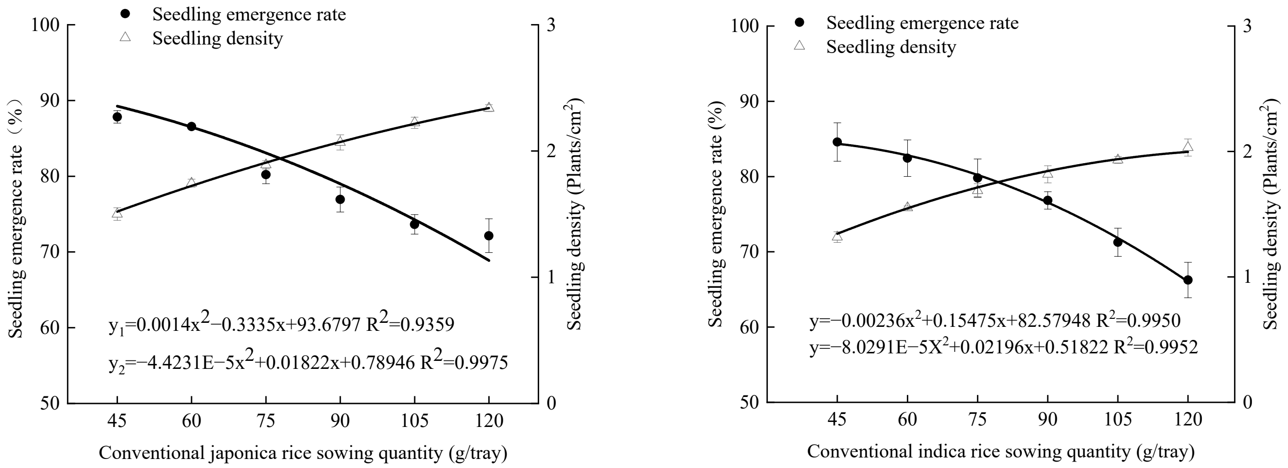

Figure 1. Effect of different conventional rice sowing quantities on the seedling population emergence rate and seedling per square centimeter. Equation y_1 is the relationship between he conventional rice sowing quantity and seedling emergence rate. Equation y_2 is the relationship between the conventional rice sowing quantity and seedling density.

3.3. Effect of Different Conventional Rice Sowing Quantities on Seedling Quality

3.3.1. Morphological Characteristics of Seedlings

With the increase in conventional rice sowing quantity, the leaf age, 100 shoot dry weight, 100 root dry weight, and mass−height ratio of rice seedlings decreased significantly, while the plant height increased significantly, and this was the case in both japonica and indica rice treatments (Table 6). Taking the 100 roots dry weight and mass−height ratio as an example, in the mixed treatment of japonica rice, the 100 roots dry weight compared with that in MJ-CK increased by 30.71% and 32.28% when the Nanjing 5055 sowing quantities were 105 g/tray (MJ-5) and 120 g/tray (MJ-6), respectively, and there was no significant difference in other treatments. Compared with MJ-CK, when the Nanjing 5055 sowing quantities were 45 g/tray (MJ-1), 60 g/tray (MJ-2), 75 g/tray (MJ-3), 90 g/tray (MJ-4), 105 g/tray (MJ-5), and 120 g/tray (MJ-6), the mass−height ratio was decreased by 5.39%, 8.02%, 14.44%, 16.96%, 31.83%, and 34.76%, respectively, among which, the 45 g/tray, 60 g/tray, 75 g/tray, and 90 g/tray had no significant difference with Changyou 4 sown

75 g/tray alone. In the mixed treatment of indica rice, the 100 roots dry weight compared with that in MI-CK increased by 32.8% when the Yangdao 6 sowing quantity was 45 g/tray (MI-1), and there was no significant difference in the other treatments. The mass−height ratio of each treatment in the indica rice mixed treatment group was higher than that of the Yuanliangyou 75 g/tray (MI-CK) sown alone. When the Yangdao 6 sowing quantities were 45 g/tray (MI-1), 60 g/tray (MI-2), 75 g/tray (MI-3), 90 g/tray (MI-4), 105 g/tray (MI-5), and 120 g/tray (MI-6), the mass height ratio was increased by 41.44%, 30.09%, 24.92%, 21.63%, 15.92%, and 13.08%, respectively. The mass−height ratios of the 45 g/tray (MI-1), 60 g/tray (MI-2), and 75 g/tray (MI-3) were significantly higher than that of Yuanliangyou sown at 75 g/tray (MI-CK) alone. It can be concluded that there was no significant difference when the amount of rice mixed with conventional rice was less. However, in the indica rice treatment, mixed sowing of hybrid rice and regular rice improved the seedling morphology.

Table 6. Effect of different conventional rice sowing quantities on the morphological characteristics of seedlings.

Treatment	Conventional Sowing Quantity (g/tray)	Plant Height(cm)	Leaf Age (Leaves)	Seedling Stems Wide (mm)	100 Shoots Dry Weight (g)	100 Roots Dry Weight (g)	Mass-Height Ratio (mg·cm^{-1})
MJ-1	45	12.41 ± 0.37 c	3.02 ± 0.08 a	2.08 ± 0.08 a	1.85 ± 0.03 ab	1.14 ± 0.06 ab	1.50 ± 0.09 ab
MJ-2	60	12.63 ± 0.42 bc	3.02 ± 0.09 a	2.07 ± 0.08 a	1.81 ± 0.06 ab	1.10 ± 0.07 ab	1.46 ± 0.15 ab
MJ-3	75	12.70 ± 0.32 bc	3.00 ± 0.09 a	1.96 ± 0.06 a	1.68 ± 0.12 bcd	1.00 ± 0.04 ab	1.36 ± 0.21 ab
MJ-4	90	13.05 ± 0.26 bc	2.77 ± 0.10 ab	1.85 ± 0.07 ab	1.71 ± 0.07 bc	0.96 ± 0.10 ab	1.32 ± 0.11 ab
MJ-5	105	13.46 ± 0.23 b	2.78 ± 0.10 ab	1.72 ± 0.08 b	1.45 ± 0.04 d	0.88 ± 0.08 b	1.08 ± 0.03 b
MJ-6	120	14.49 ± 0.34 a	2.72 ± 0.11 b	1.68 ± 0.07 b	1.47 ± 0.08 cd	0.86 ± 0.05 b	1.04 ± 0.14 b
MJ-CK	0	13.03 ± 0.39 bc	3.03 ± 0.07 a	2.04 ± 0.10 a	2.03 ± 0.08 a	1.27 ± 0.22 a	1.59 ± 0.19 a
MI-1	45	13.02 ± 0.27 c	3.18 ± 0.07 a	2.14 ± 0.09 a	2.12 ± 0.08 a	0.85 ± 0.03 a	1.63 ± 0.05 a
MI-2	60	13.34 ± 0.25 bc	3.12 ± 0.04 ab	2.16 ± 0.08 a	2.14 ± 0.05 a	0.80 ± 0.03 ab	1.60 ± 0.04 a
MI-3	75	14.28 ± 0.37 ab	3.05 ± 0.03 ab	2.10 ± 0.06 a	2.05 ± 0.04 a	0.73 ± 0.03 ab	1.44 ± 0.05 ab
MI-4	90	14.62 ± 0.48 a	3.05 ± 0.06 ab	2.11 ± 0.05 a	2.04 ± 0.22 ab	0.74 ± 0.03 ab	1.40 ± 0.17 abc
MI-5	105	14.70 ± 0.41 a	3.07 ± 0.04 ab	2.05 ± 0.08 a	1.95 ± 0.02 ab	0.71 ± 0.07 ab	1.33 ± 0.05 bc
MI-6	120	14.73 ± 0.47 a	2.97 ± 0.10 bc	2.02 ± 0.06 a	1.91 ± 0.07 ab	0.71 ± 0.04 ab	1.30 ± 0.08 bc
MI-CK	0	14.47 ± 0.35 a	2.82 ± 0.06 c	2.08 ± 0.09 a	1.66 ± 0.07 b	0.64 ± 0.09 b	1.15 ± 0.06 c

MJ-1–MJ-6 indicate 30 g/tray Changyou 4 seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Nanjing 5055 seeds, respectively. MI-1–MI-6 indicate 30 g/tray Yuanliangyou seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Yangdao 6 seeds, respectively. MJ-CK and MI-CK indicate Changyou 4 and Yuanliangyou separately sown at 75 g/tray. For a given subspecies, values (mean ± SD) followed by different letters are significantly different at $p < 0.05$.

3.3.2. Root System Characteristics of Seedlings

In the mixed sowing treatment, the length of the longest root, white root number per plant, and root growth ability in water decreased with increasing the conventional rice sowing quantity. The root system characteristics of the seedlings were better than those of the conventional control when the conventional rice sowing quantity was low, but were weaker than those of the conventional control when the conventional rice sowing quantity was high (Table 7). Taking the root growth ability in water as an example, in the japonica rice treatment, the root growth ability in water compared with that in MJ-CK increased by 70.59%, 50.94%, 43.29%, and 8.43% when the Nanjing 5055 sowing quantities were 45 g/tray (MJ-1), 60 g/tray (MJ-2), 75 g/tray (MJ-3), and 90 g/tray (MJ-4), respectively. However, when the Nanjing 5055 sowing quantities were 105 g/tray (MJ-5) and 120 g/tray (MJ-6), the root growth ability in water compared with the MJ-CK decreased by 7.9% and 10.59%, respectively. In the treatment of indica rice, when the Yangdao 6 sowing quantities were 45 g/tray (MI-1), 60 g/tray (MI-2), 75 g/tray (MI-3), 90 g/tray (MI-4), and 105 g/tray (MI-5), the root growth ability in water was 43.42%, 39.46%, 33.52%, 21.01%, and 5.24% higher than that of the MI-CK, respectively. In conclusion, the method of blending conventional rice into hybrid rice can improve the root growth ability of seedlings, but the conventional rice sowing quantity should not be too large.

Table 7. Effect of different contents of conventional rice sown on the population root system characteristics of seedlings.

Treatment	Convention al Sowing Quantity (g/tray)	The Length of Longest Roots (cm)	White Root Number per Plant	Rooting Ability (cm)	Root Entwining Force (kg)
MJ-1	45	8.48 ± 0.84 a	10.80 ± 0.44 a	14.50 ± 1.83 a	9.17 ± 0.47 e
MJ-2	60	7.89 ± 0.64 ab	10.40 ± 0.37 ab	12.83 ± 0.56 ab	9.52 ± 0.19 de
MJ-3	75	6.80 ± 0.40 ab	10.11 ± 0.54 ab	12.18 ± 1.19 ab	10.13 ± 0.09 cd
MJ-4	90	6.44 ± 0.33 b	10.00 ± 0.76 ab	9.22 ± 1.55 bc	10.53 ± 0.22 bc
MJ-5	105	6.39 ± 0.37 b	9.67 ± 0.55 ab	7.83 ± 1.00 c	11.35 ± 0.32 ab
MJ-6	120	6.29 ± 0.42 b	8.83 ± 0.79 ab	7.60 ± 0.79 c	11.75 ± 0.24 a
MJ-CK	0	6.48 ± 0.22 b	8.78 ± 0.64 b	8.50 ± 1.57 cd	9.49 ± 0.17 de
MI-1	45	8.74 ± 0.60 a	15.33 ± 0.76 a	10.24 ± 2.16 a	7.04 ± 0.48 d
MI-2	60	8.41 ± 0.72 ab	15.29 ± 1.60 a	9.96 ± 1.82 a	7.91 ± 0.18 cd
MI-3	75	8.21 ± 0.43 ab	15.22 ± 0.43 a	9.53 ± 2.90 ab	8.85 ± 0.35 c
MI-4	90	7.13 ± 0.38 abc	14.70 ± 0.78 a	8.64 ± 1.83 ab	9.93 ± 0.66 b
MI-5	105	6.77 ± 0.74 bc	14.60 ± 0.60 a	7.51 ± 1.31 ab	10.76 ± 0.57 ab
MI-6	120	5.80 ± 0.52 c	13.50 ± 0.93 a	3.62 ± 0.60 b	11.31 ± 0.64 a
MI-CK	0	6.67 ± 0.44 abc	13.10 ± 0.48 a	7.14 ± 1.01 ab	6.91 ± 0.41 d

MJ-1–MJ-6 indicate 30 g/tray Changyou 4 seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Nanjing 5055 seeds, respectively. MI-1–MI-6 indicate 30 g/tray Yuanliangyou seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Yangdao 6 seeds, respectively. MJ-CK and MI-CK indicate Changyou 4 and Yuanliangyou separately sown at 75 g/tray. For a given subspecies, values (mean ± SD) followed by different letters are significantly different at $p < 0.05$.

The root entwining force is an important evaluation index of flat seedling formation, and seedlings with a better root entwining coiling force are blanket shaped, which is conducive to transport and machine insertion. In the japonica rice treatment, the root entwining force of the Nanjing 5055 sowing quantity of 45 g/tray (MJ-1) was slightly lower than that of the conventional control (MJ-CK), and all the other treatments were higher than that of the MJ-CK. In the indica rice treatment, all of the treatments had a greater root entwining force than the conventional control (MI-CK) (Table 7). There was a significant positive correlation between the root entwining force and sowing quantity. After the regression analysis, the root entwining force showed a strong logarithmic correlation with the content of the conventional rice sowing quantity, and the correlation coefficients of the japonica and indica rice treatments were 0.974 and 0.994, respectively (Figure 2). The results indicated that the content of conventional rice added to hybrid rice could effectively improve the root entwining force, but at higher incorporation amounts, the increased rate of the root entwining force decreased with increasing the conventional rice sowing quantity. However, the effect of continuing to add regular rice on the root entwining force was not obvious when the content of conventional rice added was high. In addition, the roots of the japonica rice treatment were higher than those of the indica rice treatment, indicating that the root density of Changyou 4 mixed with Nanjing 5055 in the flat seedlings was higher than that of Yuanliangyou seedlings mixed with Yangdao 6.

3.3.3. Relationship between the Different Contents of Conventional Rice Sowing Quantity and SPAD of Seedlings

The SPAD values of the japonica and indica rice treatments showed a downward trend with increasing the conventional rice sowing quantity. The SPAD value of the japonica rice treatment was higher than that of the indica rice treatment when the conventional rice sowing quantity was low, but with the increase in conventional rice sowing quantity, the SPAD values of the two types of rice gradually approached each other. In the japonica rice treatment, the SPAD value of 75 g/tray (MJ-CK) of Changyou 4 was 24.19 ± 1.1. The SPAD value of seedlings at 45 g/tray of Nanjing 5055 (MJ-1) was 5.31% higher than that of the conventional control (MJ-CK), and at 120 g/tray, it was 13.83% lower than that of the conventional control (MJ-CK). In the indica rice treatment, the SPAD value of 75 g/tray (MI-CK) of Yuanliangyou was 24.19 ± 1.1. The SPAD value of seedlings at 45 g/tray of Yangdao 6 (MI-1) was 5.31% higher than that of the conventional control (MI-CK), and that at 120 g/tray (MI-6) was 13.83% lower than that of the conventional control (MI-CK). The regression analysis between SPAD value and sowing quantity of japonica rice and indica rice showed that there was a significant logarithmic correlation between SPAD value and conventional rice sowing quantity in japonica rice and indica rice treatments, and the correlation coefficients reached 0.943 and 0.999, respectively. The results showed that there was a significant negative correlation between the SPAD value and the conventional rice sowing quantity. In addition, the SPAD value of the seedlings was greatly affected when the conventional rice sowing quantity was low, while the SPAD value was not affected much when the conventional rice sowing quantity was high (Figure 3).

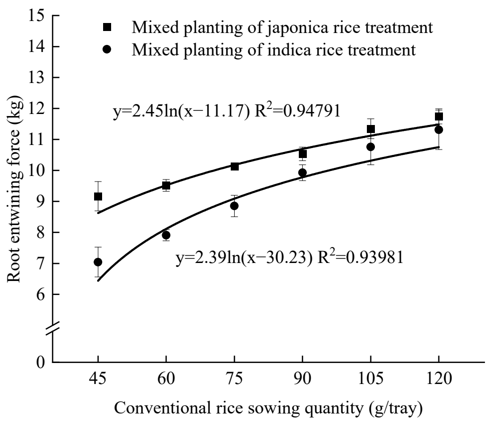

Figure 2. Relationship between the different contents of conventional rice sowing quantity and root entwining force.

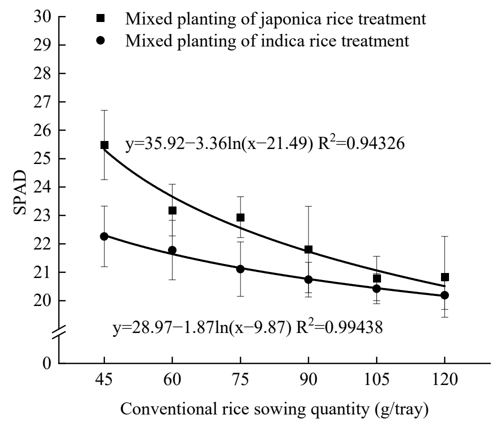

Figure 3. Relationship between the different conventional rice sowing quantities and SPAD of seedlings.

3.4. Effect of Different Conventional Rice Sowing Quantities on the Mechanical Transplanting Effect and Machine Insertion Quality

The japonica rice treatment and indica rice treatment showed the same performance in terms of the mechanical transplanting effect and machine insertion quality (Table 8). With the increase in the conventional rice sowing quantity, the missing hill rate decreased significantly, while the floating seedling rate and the number of seedlings per hill increased significantly. The seedling damage rate and overturned seedling rate showed an increasing trend, but there was no significant difference. The missing hill rate of MJ-1 to MJ-6 in the japonica rice mixed treatment was reduced by 9.52%, 16.67%, 30.09%, 48.40%, 64.33%, and 70.38%, respectively, compared with that of conventional sowing of the Changyou 4 75 g/tray (MJ-CK) alone. The number of seedlings per hill increased by 3.33%, 11.67%, 16.67%, 36.67%, 50%, and 73.33%, respectively, compared with Changyou 4 sown alone (MJ-CK). In the indica rice mixed treatment combination, compared with the conventional control Yuanliangyou seedlings sown at 75 g/tray (MI-CK), the missing hill rates of MI-1 to MI-6 treatments were reduced by 16.02%, 24.66%, 38.48%, 41.86%, 62.42%, and 71.21%, respectively. Compared with the MI-CK, the seedlings per hill in MI-1 and MI-2 decreased by 16.42% and 7.46%, while the seedlings per hill in MI-3, MI-4, MI-5, and MI-6 increased by 5.97%, 13.43%, 31.34%, and 41.79%, respectively. The results indicated that when hybrid rice and conventional rice were mixed-cropped, increasing the conventional rice sowing quantity could effectively reduce the missing hill rate of mechanical transplanting and had little effect on the damaged seedling rate and overturned seedling rate, but increased the number of seedlings per hill. The number of seedlings per unit area was negatively correlated with the missing hill rate and positively correlated with the seedlings per hill (Figure 4).

Table 8. Effect of different conventional rice sowing quantities on the mechanical transplanting effect and machine insertion quality.

Treatment	Conventional Sowing Quantity (g/tray)	Missing Hill Rate (%)	Floating Seedling Rate (%)	Damaged Seedling Rate (%)	Overturned Seedling Rate (%)	Seedling per Hill
MJ-1	45	12.67 ± 0.67 ab	5.00 ± 1.83 b	0.67 ± 0.67 a	1.17 ± 0.40 a	3.10 ± 0.22 cd
MJ-2	60	11.67 ± 0.88 bc	6.67 ± 1.67 ab	0.72 ± 0.72 a	1.50 ± 0.22 a	3.35 ± 0.26 cd
MJ-3	75	9.79 ± 0.79 c	5.83 ± 1.54 b	0.95 ± 0.60 a	1.67 ± 0.33 a	3.50 ± 0.26 cd
MJ-4	90	7.22 ± 0.40 d	7.50 ± 2.14 ab	1.03 ± 0.66 a	1.83 ± 0.40 a	4.10 ± 0.33 bc
MJ-5	105	4.99 ± 0.57 e	9.17 ± 1.54 ab	1.11 ± 0.70 a	1.83 ± 0.60 a	4.50 ± 0.42 b
MJ-6	120	4.15 ± 0.15 e	11.67 ± 1.05 a	1.33 ± 0.84 a	2.00 ± 0.97 a	5.20 ± 0.43 a
MJ-CK	0	14.00 ± 1.00 a	6.67 ± 1.05 ab	0.83 ± 0.83 a	1.67 ± 0.42 a	3.00 ± 0.34 d
MI-1	45	7.78 ± 0.40 ab	3.33 ± 1.67 a	0.33 ± 0.33 a	0.83 ± 0.31 b	2.80 ± 0.31 c
MI-2	60	6.98 ± 0.98 ab	5.00 ± 2.24 a	0.67 ± 0.42 a	1.00 ± 0.37 b	3.10 ± 0.31 c
MI-3	75	5.70 ± 0.74 bc	5.00 ± 1.83 a	0.67 ± 0.42 a	1.00 ± 0.37 b	3.55 ± 0.40 bc
MI-4	90	5.38 ± 1.22 bc	5.00 ± 1.83 a	0.67 ± 0.42 a	1.33 ± 0.21 ab	3.80 ± 0.48 abc
MI-5	105	3.48 ± 0.42 cd	7.50 ± 1.71 a	1.00 ± 0.45 a	1.67 ± 0.21 ab	4.40 ± 0.45 ab
MI-6	120	2.67 ± 0.33 d	7.50 ± 2.14 a	2.00 ± 0.73 a	2.17 ± 0.48 a	4.75 ± 0.38 a
MI-CK	0	9.26 ± 0.94 a	4.17 ± 2.39 a	0.33 ± 0.33 a	0.83 ± 0.40 b	3.35 ± 0.34 bc

MJ-1–MJ-6 indicate 30 g/tray Changyou 4 seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Nanjing 5055 seeds, respectively. MI-1–MI-6 indicate 30 g/tray Yuanliangyou seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Yangdao 6 seeds, respectively. MJ-CK and MI-CK indicate Changyou 4 and Yuanliangyou separately sown at 75 g/tray. For a given subspecies, values (mean ± SD) followed by different letters are significantly different at $p < 0.05$.

3.5. Effect of Different Conventional Rice Sowing Quantities on the Grain Yield and Yield Components

The yield components were significantly affected by the treatments, but there was no significant affected of year ($p = 0.980$, $p = 0.519$, $p = 0.796$, and $p = 0.359$, respectively) and interaction effect ($p = 0.834$, $p = 0.317$, $p = 0.803$, $p = 0.601$, and $p = 0.893$, respectively) between year and treatment (Table 9). Japonica rice treatments and indica rice treatments showed the same grain yield, which increased first and then decreased with the increase in conventional rice sowing quantity. There was no significant difference in the grain yield of Nanjing 5055 when the sowing quantity was more than 75 g/tray compared with Changyou 4 when it was sown alone 75 g/tray (MJ-CK), but their grain yields were significantly increased compared with the minimum sowing quantity (MJ-1) by 4.23%, 5.78%, and 5.57%, respectively. There was no significant difference between the yield of Yangdao 6 sown more than 60 g/tray and that of Yuanliangyou sown alone 75 g/tray (MI-CK), but it was significantly higher than that of the low sowing quantity treatments (MI-1 and MI-2). Their grain yields increased by 8.79%, 8.46%, 8.20%, and 7.91%, respectively, compared with MI-1, and increased by 4.17%, 3.86%, 3.61%, and 3.33% respectively compared with MI-2. In the japonica rice treatments, although the spikelet per panicle and filled kernel percentage decreased significantly with the increase in conventional rice sowing quantity, the panicle number and 1000-grain weight increased significantly, which was the main reason the grain yield of treatments of the Nanjing 5055 sowing quantity more than 75 g/tray were not significantly different compared with the conventional control treatment (MJ-CK). In treatments of indica rice, with the increase in conventional rice sowing quantity, the spikelet per panicle, filled kernel percentage, and 1000-grain weight decreased significantly, but the panicle number increased significantly, which was the main reason the grain yield of Yangdao 6 with sowing quantity more than 60 g/tray was not significantly different compared with the conventional control treatment (MI-CK).

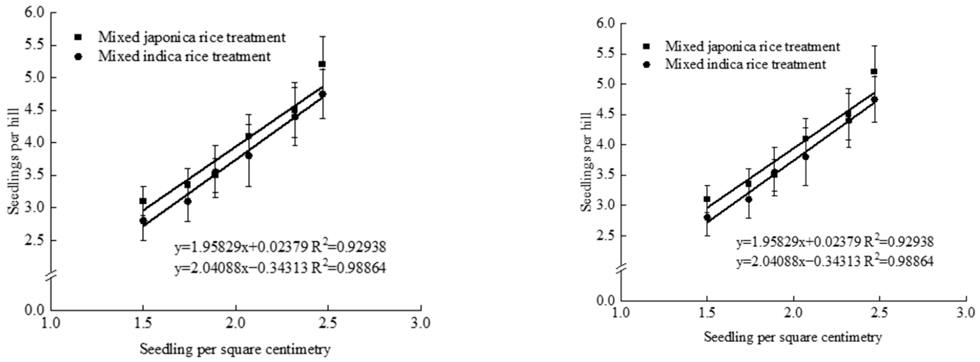

Figure 4. The relationship between the number of seedlings per unit area and the missing hill rate inserted by machine and the relationship between the number of seedlings per unit area and the number of seedlings per hill.

Table 9. Effect of different conventional rice sowing quantities on the grain yield and yield components.

Treatment	Conventional Sowing Quantity (g/tray)	Panicle Number m^{-2}	Spikelet per Panicle	Filled Kernel Percentage (%)	1000-Grain Weight (g)	Grain Yield ($t\ ha^{-1}$)
MJ-1	45	279.63 ± 11.01 c	156.37 ± 7.29	89.59 ± 0.37	25.08 ± 0.06 d	9.69 ± 0.10 c
MJ-2	60	293.06 ± 11.95 c	149.67 ± 7.01 b	88.66 ± 0.04	25.61 ± 0.19 c	9.81 ± 0.02 bc
MJ-3	75	323.15 ± 8.95 b	136.44 ± 5.69 bc	86.88 ± 0.54	26.39 ± 0.08 b	9.87 ± 0.08 bc
MJ-4(AVE)	90	348.38 ± 12.37 b	131.93 ± 6.23 bc	85.28 ± 0.34 b	26.64 ± 0.06 b	10.10 ± 0.10 b
MJ-5	105	351.39 ± 5.73	128.89 ± 6.79 c	84.61 ± 0.74 c	26.91 ± 0.07	10.25 ± 0.08
MJ-6	120	363.89 ± 6.80	123.04 ± 5.71 c	84.53 ± 0.62 c	27.11 ± 0.07	10.23 ± 0.06
MJ-CK(AVE)	0	321.76 ± 9.65 b	161.11 ± 5.06	82.71 ± 0.21 d	24.09 ± 0.06 e	10.21 ± 0.13
MI-1	45	202.31 ± 10.26 e	190.27 ± 6.41	89.07 ± 0.51	26.56 ± 0.13 b	9.02 ± 0.06 c
MI-2	60	235.19 ± 4.87 d	174.62 ± 5.70 b	87.39 ± 0.57 bc	26.46 ± 0.06 b	9.42 ± 0.04 b
MI-3	75	256.94 ± 9.99 c	170.16 ± 6.16 b	86.27 ± 0.59 cd	26.06 ± 0.09 c	9.81 ± 0.02
MI-4(AVE)	90	274.77 ± 18.41 bc	158.84 ± 6.41 bc	85.69 ± 0.43 d	25.82 ± 0.07 c	9.78 ± 0.08
MI-5	105	294.91 ± 7.37 b	149.57 ± 6.49 c	85.10 ± 0.51 d	25.80 ± 0.07 c	9.76 ± 0.12
MI-6	120	303.24 ± 6.87	146.05 ± 6.28 c	84.76 ± 0.40 d	25.74 ± 0.18 c	9.73 ± 0.11
MI-CK(AVE)	0	219.26 ± 7.08de	188.86 ± 6.58	88.23 ± 0.58 b	26.84 ± 0.10	9.77 ± 0.02

MJ-1–MJ-6 indicate 30 g/tray Changyou 4 seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Nanjing 5055 seeds, respectively. MI-1–MI-6 indicate 30 g/tray Yuanliangyou seeds mixed with 45, 60, 75, 90, 105, and 120 g/tray Yangdao 6 seeds, respectively. MJ-CK and MI-CK indicate Changyou 4 and Yuanliangyou separately sown at 75 g/tray. There were no significant effects of year and interaction effect between year and treatment on the panicle number, spikelet per panicle, filled kernel percentage, 1000-grain weight, and grain yield of MJ-4, MJ-CK, MI-4, and MI-CK between the variety matching experiment and sowing quantity of conventional rice experiment. Therefore, the yield data of MJ-4(AVE), MJ-CK(AVE), MI-4(AVE), and MI-CK(AVE) were averaged over the years. For a given subspecies, values (mean ± SD) followed by different letters are significantly different at $p < 0.05$.

4. Discussion

China's rice production is in the unprecedented period of transition to mechanization [25]. Reducing sowing quantity is critical for hybrid rice in order to adapt to the period of transition [26]. In this study, a mixed sowing and planting technology (replacement of a portion of hybrid rice seeds with conventional rice seeds) was adopted to reduce the hybrid rice sowing quantity. Rice mixed planting has been widely used for rice blast disease resistance, lodging resistance, resistance to insects, and weed resistance, and has achieved good results [27–29]. However, there is no research on the effect of rice mixed planting on the machine transplanting adaptability and grain yield of hybrid rice.

Selection of varieties is the first step of rice mixed planting. In rice mixed planting, the requirements for variety combinations are different for different results [21]. Li and Rao [30] found that the mixture of cultivars with different resistance to rice blast had a better disease resistance. Yuan and his partner [31] mixed rice plants of different plant heights and found that the lodging rates were significantly lower than when they were planted alone. Our study showed that the grain yield of different variety combinations was also different. The grain yield of Changyoujing 6, Jiayouzhongke 1, Dexiang 4013, and Yixiangyou 2115 mixed planting treatments were significantly lower than their own conventional control (Table 6). However, there were no significant differences in the grain yield of the mixed planting treatments of Changyou 4 compared with the 75 g/tray single planting of Changyou 4. The grain yield of the mixed treatments of Yuanliangyou were significantly higher than that of the single 75 g/tray planting. Although the spikelet per panicle of Changyou 4 mixed planting treatments were significantly lower than that of the conventional control treatment, they had a higher filled kernel percentage and 1000-grain weight, making up for the shortage in spikelet per panicle, which was the main reason the grain yield of the Changyou 4 mixed planting treatments were not significantly different compared with that of the conventional control. However, there is a general worry that different matching proportions will lead to different results in mixed crop production [32,33]. Interestingly, we did not observe such a phenomenon in the present study. This phenomenon may be due to the small difference in the mixed proportion between two mixed proportion treatments. Considering that the price of hybrid rice seeds is higher than that of conventional rice seeds, it is better to use 30 g Changyou 4 seeds per tray or 30 g Yuanliangyou seeds per tray.

Different seeding quantities have different effects on rice seedling quality, mechanical transplanting quality, and grain yield [11,34,35]. Although the quality of machine transplanting can be improved when the seeding quantity is too large, it will lead to the problems of poor seedling quality, increased cost input, and even decreased grain yield [36,37]. However, the seedling quality can be improved when the seeding quantity is too small, but it will lead to problems of poor machine transplanting quality, the basic seedlings are insufficient, and the panicle number is not enough to decline the grain yield [38]. Only the appropriate sowing quantity can bring high yield and higher economic benefits [39]. Here, in the conventional rice sowing quantity experiment, there was no significant difference in the grain yield of japonica rice treatments when the sowing quantity of Nanjing 5055 was more than 75 g/tray, and there was no significant difference compared with the conventional control treatment, but it was significantly higher than the treatment of 45 g/tray. The low missing hill rate and high seedling density increased their panicle number, and the increase in the proportion of Nanjing 5055 increased the 1000-grain weight, making up for the shortage of spikelet per panicle and filled kernel percentage. There was no significant difference in the grain yield of the indica rice treatments when the sowing quantity of Yangdao 6 was more than 60 g/tray, and there was no significant difference compared with the conventional control treatment, but it was significantly higher than that of 45 g/tray and 60 g/tray. Similar to japonica rice, their low missing hill rate and high seedling density increased their panicle number, making up for the shortage in spikelet per panicle, filled kernel percentage, and 1000-grain weight. In addition, the final economic benefits should also be considered in the selection of the optimal seeding quantity in actual production. In this study, when the conventional rice seed sowing quantity was too large, the rice grain yield did not increase significantly, but the production input (conventional rice sowing quantity) increased, which would affect the final economic benefits [12]. Therefore, the best conventional rice sowing quantities were 90 g/tray for Nanjing 5055 and 75 g/tray for Yangdao 6.

5. Conclusions

Conventional rice seeds were used to replace some hybrid rice seeds, which reduced the hybrid rice sowing quantity, increased the root entwining force and seedling density, reduced the missing rate, and finally improved the mechanical transplanting quality of hybrid rice. Through a variety matching experiment and conventional rice sowing quantity experiment, our study found that the mixture of Changyou 4 and Nanjing 5055, and the mixture of Yuanliangyou and Yangdao 6, would not cause a yield decline, and the seed sowing quantity of the hybrid rice was less when Changyou 4 or Yuanliangyou were both 30 g/tray. The varieties of these two combinations had a similar plant height and whole growth period, and were suitable for hybrid rice and conventional rice mixed planting. Under the present condition, 30 g Changyou 4 mixed with 90 g Nanjing 5055 in each tray, and 30 g Yuanliangyou mixed with 75 g Yangdao 6 in each tray, which can coordinate the relationship between individuals and populations, reduced the missing hill rate while cultivating strong seedlings, and reduced the cost (reduce the sowing amount of hybrid rice), ensuring a high grain yield of rice, and increasing the final income.

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