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Delayed Sowing under the Same Transplanting Date Shortened the Growth Period of Machine-Transplanted Early-Season Rice with No Significant Yield Reduction Caused

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Abstract: In early rice cultivation, the age of seedlings plays a crucial role in ensuring the annual safety production of double-cropping rice. When sowing staging and transplanting are performed simultaneously, it is still necessary to gather more data about the effects of seedling age on the growth period and grain yield of early rice machines transplanted. Two years ago, field experiments were conducted on machine-transplanted rice seedlings in the early season to compare the growth duration, crop growth characteristics, and yield attributes between the 18-day-old seedlings (SA18) and 32-day-old seedlings (SA32) of two rice cultivars. As a result of the study, it was found that SA18 reduced the total crop duration by between 11 and 12 days but delayed the maturity date by 2–3 days compared to SA32. SA18 had 14.5% fewer panicles per m^2 and 3.6% less harvest index but 7.5% more spikelets per panicle higher than SA32. The grain yield of SA18 was 3.4% less than that of SA32, but there was no significant difference between the two seedling ages. The machine-transplanted seedlings for early rice production are more efficient in reducing seedling management time without affecting harvesting time and yields. The authors provide a new cultivation management scheme for farmers who are interested in planting double-cropping rice at the same time.

Keywords: seedling age; machine transplanting; grain yield; growth period; early rice

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1. Introduction

Rice is the primary food source for over 65% of the Chinese population, making its production crucial for ensuring national food security [1,2]. Expanding the cultivated land area, increasing the yield per unit area, and increasing the multiple cropping index are three strategies for increasing yield [3]. Double-cropping rice planting effectively increases grain yield because it is difficult to improve the existing cultivated land area and significantly increase the yield per unit area [4,5]. Studies have shown that double-cropping rice yields about 57% higher than rice planted in only one season [6]. However, the characteristics of double-cropping rice that requires being planted twice in the same plot within one year, resulting in a longer production cycle, are a more tight connection between the seasons and a higher demand for labor compared to a single season, which hinders the willingness of farmers to plant double cropping rice [7]. As a result, the planting area for double-cropping rice has declined in recent decades, as farmers prefer to plant single-cropping rice for its higher yield and better quality [8–10].

In recent years, mechanized transplanting has become increasingly popular due to its ability to reduce labor intensity and save time [11]. This method provides effective support for double-cropping rice production, but it also poses some challenges [12,13].

Machine transplanting often requires higher-density sowing to meet seedling cultivation and transplanting requirements, resulting in limited space for seedling growth. As a result, machine-transplanted seedlings have a smaller age elasticity than traditionally cultivated seedlings [14,15]. For example, conventional machine-transplanted rice has a 10–15 day shorter seedling age compared to traditional rice [16].

For double-cropping rice production, planning sowing and transplanting times is critical. Especially for machine-inserted early rice, sowing too early can increase the risk of late-spring coldness during early rice cultivation and result in excessive seedling age, while sowing too late delays the harvest time of early rice and makes it difficult to connect the late rice stubble [17]. At the same time, the adverse effects of prolonged seedling age are also worthy of attention. A long seedling period not only leads to the deterioration of seedling quality but also inhibits plant growth and yield formation after transplanting [18]. Moreover, studies have indicated that when the seedling age exceeds 40 days, it can result in premature heading, affecting the double-cropping rice yield [19]. Recently, studies have shown that precision sowing can prolong seedling age without compromising yield [12,20]. However, this technology is still in the early stages of adoption, given the equipment renewal cost and farmers' acceptance. The above reasons have intensified the difficulty of choosing machine-transplanted double-cropping rice's sowing and transplanting times. It was further confirmed that selecting sowing and transplanting times for machine-transplanted early rice is crucial to ensuring safe and productive double-cropping rice production.

However, in the actual production practice of double-season early rice, farmers are accustomed to sowing early rice as early as possible to obtain sufficient a growth cycle to ensure the safe full heading of late rice, which increases the cost of seedling management and the possibility of low-temperature stress at the early rice seedling stage, bringing about production instability factors [21]. A low temperature during rice seedling rearing slows seedling growth, and prolonging the seedling's age harms machine-inserted rice seedlings. When early rice is machine-inserted and transplanted uniformly, we assume that delayed sowing does not affect the harvest time or yield. Two-year field experiments were conducted to determine how the timing of sowing, simultaneous transplanting, and machine-transplanted early rice growth affected the growth period, growth characteristics, and yield.

2. Materials and Methods

2.1. Experimental Site and Cultivar Description

Field experiments were conducted in Yanxi Town (28°18′ N, 113°49′ E), Changsha County, Hunan Province, China, in the early rice-growing seasons of 2021 and 2022. Changsha County is a typical double-season rice-growing region in the Yangtze River basin. The soil from the upper 20 cm was sampled before the initiation of the experiment, and the properties were as follows: pH = 5.67, organic matter = 14.2 g kg^{-1}, NaOH hydrolyzable N = 162.4 mg kg^{-1}, Olsen P = 16.6 mg kg^{-1}, and NH_4OAc extractable K = 94.3 mg kg^{-1}. This study used two rice varieties, Lingliangyou211 (LLY211) and Zhongzao39 (ZZ39), in 2021 and 2022. Among the two varieties, LLY211 is an indica hybrid, and ZZ39 is an indica inbred. These two varieties were selected because they are typical early rice varieties and are widely cultivated in local production.

2.2. Experimental Design and Cultivation Management

The experiment was arranged as a randomized block design with three replications in a 30 m^2 plot. Rice plants with two rice types were assigned as the main plot, with two different seedling ages (SA, representing the days from sowing to transplanting) being randomly allotted to the subplot. The two seedling ages were 32d (SA32) and 18d (SA18), respectively. The SA treatments were achieved by changing the sowing dates with the same transplanting dates in 2021 and 2022. Pre-germinated seeds were manually sown in seedling trays (58 × 22.5 cm) with a seed rate of 80 g $tray^{-1}$ on 17 March and

31 March, respectively. The rice plants were uniformly transplanted on 18 April by a high-speed rice transplanter (YR70D, Yangma Agricultural Equipment Machinery Co., Ltd., Changzhou, China). The distances between the rows and hills were 25 cm and 12 cm, with 4–5 seedlings per hill for the mechanical transplantation patterns. The crop was fertilized with 150:75:120 kg $N:P_2O_5:K_2O$ ha^{-1} as urea, calcium superphosphate, and potassium chloride, respectively. Nitrogen was applied in three splits: 60 kg N ha^{-1} as a basal fertilizer 1 day before transplanting, 45 kg N ha^{-1} at early tillering (5 days after transplanting, DAT), and 45 kg N ha^{-1} at panicle initiation. Phosphorus (75 kg P_2O_5 ha^{-1}) was applied as a basal fertilizer. Potassium (120 kg K_2O ha^{-1}) was split equally at basal fertilization and panicle initiation. The water management strategy was flooding, followed by midseason drainage to reduce unproductive tillers, re-flooding, moist intermittent irrigation, and drainage a week before maturity. Chemicals intensively controlled all crop protection practices to avoid yield loss.

2.3. Plant Sampling and Determination

We measured 100 plants during transplantation for the following criteria: seedling height, leaf age, number of green leaves, height of the first leaf pillow, height of the second leaf pillow, stem base width, and dry weights above-ground and below ground. During 2021 and 2022, the numbers of tillers in 10 fixed hills from each plot were evaluated at 5 d intervals between 5 and 45 days after the farmers transplanted the rice seedlings to the field. Meanwhile, the heading dynamics were investigated at the heading stage. The dates of the sowing (SW), transplanting (TP), initial heading (IH, 10% of panicles had emerged), full heading (FH, 80% of panicles had occurred), and maturity stages (more than 90% of grains had lost their green color) in every treatment were recorded accurately.

In the tillering stage (TI, 25 days after transplanting), jointing stage (JI, 45 days after transplanting), full heading stage (FH), and maturity stage (MA), the above-ground parts of the rice plants from 9 hills from each treatment were sampled and subsequently divided into two (leaf, and stem and sheath at the TI and JI) or three (leaf; stem and sheath; and panicle at the FH and MA) parts. The separated organs were dried at 105 °C for 0.5 h, then dried at 70 °C until constant weight, and weighed to determine the dry matter weight.

At maturity, the effective panicle number per square meter was obtained by investigating 50 consecutive hills. The spikelet $panicle^{-1}$, filling rates, and grain weight were determined by selecting 9 hills consistent with the effective panicle number. Finally, the grain yield was determined in a set of 50 hills and adjusted to the standard moisture content of 0.14 g H_2O g^{-1}, repeated 9 times.

2.4. Data Collection and Measurements

The daily air mean temperatures (MT), maximum temperatures (MaT), and minimum temperatures (MiT) during the rice growth season were obtained from a local meteorological station for both years. The effective accumulated temperature (EAT) and active accumulated temperature (AAT) were calculated as follows:

$$\mathrm{EAT}\ (^{\circ}\mathrm{C}) = \sum (\mathrm{MT} - \mathrm{T0}) \times \text{ growth duration (GD)} \tag{1}$$

$$\mathrm{AAT}\ (^{\circ}\mathrm{C}) = \sum_{i=1}^{n} (\mathrm{Ti})\mathrm{Ti} \ \geq \ \mathrm{T0}\ (\text{if Ti} \ < \ \mathrm{T0},\ \mathrm{AAT} = 0) \tag{2}$$

where T0 (10 °C for rice) is the biological zero temperature, n is the number of days for growth, and Ti is the average temperature for the day.

$$\text{Tillering rate} = (\text{maximum tillering number} - \text{basic number of seedlings})/\text{primary number of seedlings}$$

$$\text{Crop growth rate } (\mathrm{g\ m^{-2}\ d^{-1}}) = (\mathrm{w2} - \mathrm{w1})/(\mathrm{t2} - \mathrm{t1})$$

where w1 and w2 represent the dry matter weight of the population tested as measured the first and second times, respectively; the difference between t2 and t1 is the time interval of the two measurements.

2.5. Statistical Analyses

Statistical analyses were performed using analyses of variance (ANOVA) with the statistical software SPSS 20.0. The means of significant treatments were compared by using the Least Significant Difference (LSD) test at a $p < 0.05$ probability level.

3. Results

3.1. Meteorological Changes during the Growing Season

The daily maximum temperature, daily minimum temperature, daily average temperature, effective accumulated temperature, and active accumulated temperature in 2021 were 28.8 °C, 22.0 °C, 25.4 °C, 1317.3 °C, and 2167.3 °C in the field's increasing period (Figure 1a). The values for 2022 were 27.9 °C, 18.8 °C, 23.3 °C, 1170.7 °C, and 2040.7 °C, respectively (Figure 1b). Overall, these values in 2021 were significantly higher than those in 2022.

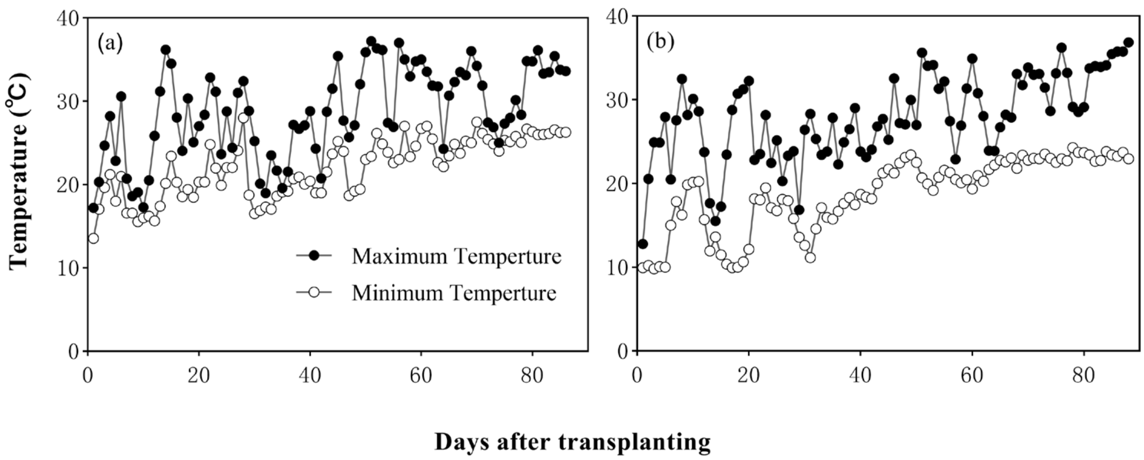

Figure 1. Meteorological changes (daily maximum temperature and minimum temperature) after transplanting in 2021 (**a**) and 2022 (**b**).

3.2. Growth Duration

For LLY211, the growth times of SA18 from sowing to initial heading and from sowing to full heading were 12 days and 14 days shorter than those of SA32, respectively, while the growth time from transplanting to initial heading was 2 days longer than that of SA32. There was no difference in transplanting to full heading between SA32 and SA18 in 2021 and 2022. For ZZ39, the growth times of SA18 from sowing to initial heading were 11 and 10 days shorter than those of SA32 in 2021 and 2022, respectively, and the growth times from sowing to full heading were 11 days shorter than those of SA32 in both years. However, the growth times of SA18 from transplanting to initial heading and full heading were 3 and 4 days longer than those of SA32 in 2021 and 2022, respectively, and the growth times from sowing to full heading were 3 days longer than those of SA32 in both years (Table 1).

Table 1. Growth duration of machine-transplanted early rice at different seedling ages in 2021 and 2022.

Year	Variety	Sowing Dates	Initial Heading Dates	Full Heading Dates	Days from SW to IH	Days from SW to FH	Days from TP to IH	Days from TP to FH	Days from SW to MA
2021	LLY211	3–17	6–9	6–18	84	93	52	61	113
		3–31	6–11	6–18	72	79	54	61	101
	ZZ39	3–17	6–10	6–17	85	92	53	60	115
		3–31	6–13	6–20	74	81	56	63	103
2022	LLY211	3–17	6–11	6–18	86	93	54	61	113
		3–31	6–13	6–18	74	79	56	61	101
	ZZ39	3–17	6–11	6–18	86	93	54	61	116
		3–31	6–15	6–21	76	82	58	64	105

LLY211 and ZZ39 are Lingliangyou 211 and Zhongzao39, respectively. SW, TP, IH, FH, and MA represent the dates of sowing, transplanting, initial heading, full heading, and maturity, respectively.

3.3. Crop Development

The tillering rate of SA32 was higher than that of SA18 by 17.2%. There were no significant differences in LAI at FH, CGR during the transplanting stage to the tillering stage, the tillering stage to the jointing stage, the jointing stage to the full heading stage, the full heading stage to the maturity stage, and the total biomass production between SA32 and SA18 (Table 2). The tillering rate and LAI at FH of LLY 211 were significantly higher than those of ZZ39 by 62.5% and 9.5%, respectively. No significant differences existed in all the tested CGR parameters and total biomass production between LLY211 and ZZ39. There were no such distinctions in biomass production at MA between 2021 and 2022. The tillering rate, LAI at FH, and CGR from the transplanting stage to the tillering stage, the tillering stage to the jointing stage, and the jointing stage to the full heading stage were higher in 2021 than in 2022 by 33.3%, 22.7%, 23.9%, 33.8%, 36.2%, and 35.1%, respectively. In contrast, CGR from the full heading stage to the maturity stage in 2021 was 40.8% lower than in 2022 (Table 2).

Table 2. Tilling rate, leaf area index (LAI) at full heading (FH), single stem dry matter, crop growth rate (CGR), and total biomass production in machine-transplanted late-season rice affected by seedling age, cultivar, and year.

Variable	Tillering Rate	LAI at FH	Single Stem Weight (g)		CGR (g m^{-2} d^{-1})				Biomass Production (g m^{-2})
			FH	MA	TP-TI	TI-JI	JI-FH	FH-MA	Total
Seedling age (SA)									
SA32	3.4 a	5.24 a	2.04 b	3.36 b	3.1 a	12.8 a	28.9 a	20.9 a	1372 a
SA18	2.9 b	5.36 a	2.24 a	3.76 a	2.9 a	13 a	28.2 a	18.9 a	1305 a
Cultivar (C)									
LLY211	3.9 a	5.54 a	1.71 b	2.96 b	3.2 a	13.4 a	28.7 a	20.6 a	1343 a
ZZ39	2.4 b	5.06 b	2.58 a	4.16 a	2.8 a	12.5 a	28.4 a	19.1 a	1334 a
Year (Y)									
2021	3.6 a	5.84 a	2.77 a	3.51 a	3.3 a	14.8 a	32.9 a	16.9 b	1357 a
2022	2.7 b	4.76 b	1.52 b	3.61 a	2.7 b	11.1 b	24.2 b	22.8 a	1321 a

Means that each variable sharing the same letter is not significantly different at the 0.05 probability level. SA32 and SA18 represent seedling ages of 32 and 18 days, respectively. LLY211 and ZZ39 are Lingliangyou 211 and Zhongzao39, respectively. TP-TI, TI-JI, JI-FH, and FH-MA represent the transplanting stage to the tillering stage, the tillering stage to the booting stage, the booting stage to the full heading stage, and the full heading stage to the maturity stage, respectively.

3.4. Grain Yield and Yield Components

There were no apparent discrepancies in grain yield, spikelet filling percentage, and grain weight between SA32 and SA18. SA32 had 16.8% higher panicles per m^2 and a 3.7% higher harvest index but 7.5% lower spikelets per panicle than SA18. There were no significant differences in the spikelet filling percentage and grain weight between LLY211 and ZZ39. However, LLY211 had a 7.7% higher grain yield, 43% higher panicles per m^2, and a 9.6% higher harvest index but 23.3% lower spikelets per panicle than ZZ39. There were no meaningful differences in the grain yield and panicles per m^2 between 2021 and 2022. The spikelets per panicle were 7.7% higher in 2021 than in 2022, whereas the spikelet-filling percentage, grain weight, and harvest index were 11.5%, 1.9%, and 3.6% lower in 2021 than in 2022, respectively (Table 3).

Table 3. Grain yield, yield components, and harvest index in machine-transplanted early-season rice affected by seedling age, year, and cultivar.

Variable	Grain Yield (t ha^{-1})	Panicles per m^2	Spikelets per Panicle	Spikelet Filling (%)	Grain Weight (mg)	Harvest Index
Seedling age (SA)						
SA32	8.28 a	417.4 a	114.6 b	70.5 a	26.2 a	0.56 a
SA18	8 a	357 b	123.2 a	70.2 a	26 a	0.54 b
Cultivar (C)						
LLY211	8.44 a	456.2 a	103.3 b	71.1 a	25.9 a	0.57 a
ZZ39	7.84 b	318.3 b	134.5 a	69.7 a	26.2 a	0.52 b
Year (Y)						
2021	8.02 a	400.9 a	123.3 a	66.1 b	25.8 b	0.54 b
2022	8.26 a	373.6 a	114.5 b	74.7 a	26.3 a	0.56 a

Means that each variable sharing the same letter is not significantly different at the 0.05 probability level. SA32 and SA18 represent seedling ages of 32 and 18 days, respectively; LLY211 and ZZ39 are Lingliangyou 211 and Zhongzao39, respectively.

4. Discussion

Selecting early and late rice varieties with reasonable growth periods is one of the primary considerations and key technologies for double-cropping rice production [22]. The growth period is determined by genotype and is closely related to the allocation of temperature and light resources [23]. The dislocation of sowing and transplanting changes the temperature and light conditions during rice growth. The response of the growth period to sowing and transplanting time was highly variable in previous studies [24]. However, the effect of planting time on the growth period will be different due to the differences in research methods. It was found that when the transplanting age was 20 days, delaying sowing for 15 days shortened the transplanting days to the full heading stage by 6 days and the whole growth period by 3 days, but the maturity period was delayed by 11–12 days [14]. Some studies have shown that when the sowing is delayed by 14 days, the full heading date is delayed by 1–4 days, the ripening date is delayed by 1–2 days, and the growing season of the field is shortened by 13–15 days [25]. In this study, similar results were obtained. Compared to SA32, SA18 extended the growing period (from transplanting to ripening) by 2–3 days but shortened the whole growth period (from sowing to ripening) by 11–12 days. This indicates that when the transplanting date is consistent, the appropriate postponement of sowing has little effect on machine-inserted early-rice harvest time. In addition, given that the temperature and light conditions and water and fertilizer management were almost the same after transplanting in this study, we speculated that the transplanting to maturity time was only 2–3 days between SA18 and SA32, which may be attributed to the following two factors: (1) SA32 has more transplanting severe damage, leading to a longer greening period than that of SA18 [26], and (2) SA18 has a faster development rate than that of SA32 after transplanting [27].

The grain yield responses to seedling age were highly variable in previous studies [24]. Among them, most studies posited that a prolonged seedling period would cause a yield decline, and the main reason was that the effective panicle number, grain number per panicle, and 1000-grain weight decreased significantly [28]. However, we did not observe a significant difference in grain yield between SA18 and SA32 in this study. Notably, the number of panicles per m^2 and harvest index of SA18 were significantly lower than that of SA32, while the number of grains per panicle was considerably higher. This finding contradicts the conclusion drawn by Li Yuxiang et al. [25]. We hypothesize that this discrepancy may be attributable to two factors: firstly, due to the decrease in temperature from SW to TP, the growth rate of the seedlings slowed down, resulting in a minimal disparity between the actual development processes of SA18 and SA32; secondly, it may be related to the fact that we improved the sowing uniformity as much as possible at the time of sowing because it has been proved that the yield of early rice with precision sowing will not be reduced by extending the seedling age [16].

The rice yield differed by including genetic cultivars [29] and rice growing in agro-climatic conditions. A significant distinction in grain yield was observed between the cultivars in this study. LLY211 exhibited higher productivity compared to ZZ39, primarily due to its more substantial number of panicles per m^2 and higher harvest index. These findings highlight the importance of genotype in determining yield performance, suggesting that selecting cultivars with more panicles per m^2 and a higher harvest index may be a feasible way of increasing the grain yield in machine-transplanted early-season rice. Additionally, there was a slight decrease in grain yield in 2021 compared to 2022. This may be mainly attributed to the more suitable meteorological conditions 2022, which promoted increased spikelet filling rate, grain weight, and harvest index.

It is widely acknowledged that leaf area index (LAI) is crucial in material production [30,31]. In this study, No significant difference was observed in the LAI at FH and the biomass production at MA between SA18 and SA32. However, it should be noted that SA32 exhibited a higher tillering rate but a lower single-stem dry matter compared to SA18. This can be attributed to two reasons: (1) the advantage of SA32 in tiller number disappeared as crop growth progressed, and (2) SA18 outperformed SA32 in striving for large ear formation. This also suggests a possible equilibrium mechanism between the number of panicles and spikelets per panicle.

Furthermore, although we did not statistically analyze the management cost of seedling rearing, it is evident that SA18 significantly reduced the seedling rearing time by 14d compared to SA32. Therefore, when considering comprehensive production benefits, future studies should focus more on the potential management costs and unknown meteorological risk factors during this period.

5. Conclusions

Our study suggests that rice maturity will be delayed by 2–3 days when the transplanting date is constant if delayed sowing is made. This may be due to the ability of the rice plants to adjust to the changing environment. To compensate for delayed sowing, rice plants can adjust their growth and tillering rates. As a result, they can maintain yield despite a delay in transplanting. According to the study, a proper delay in sowing does not adversely affect harvest timing or yield of machine-inserted early rice, and these findings provide valuable insights into determining the optimal planting time. According to the study, delaying sowing by up to 10 days did not affect the harvest timing or yield, which indicates that the best time to plant machine-inserted early rice is later than the traditional planting date, allowing the rice to mature sufficiently before harvest.

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