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Effects of Postponing Topdressing-N on the Yield of Different Types of *japonica* Rice and Its Relationship with Soil Fertility

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Abstract: N fertilizer is usually supplied via multiple applications in rice production in China. Due to the high N-recovery efficiency (NRE) of panicle fertilizer, applying large amounts of fertilizer at the booting stage is considered to be an effective measure of increasing yields, although it has adverse effects on eating quality. In this study, using six inbred and four hybrid *japonica* varieties, we postponed topdressing-N to increase the ratio of panicle N from 20% to 40% by correspondingly reducing the N amount applied only at the tillering stage. We also analyzed the effects of postponing the topdressing-N on grain yield and dry matter accumulation in both high- and low-fertility blue clayey paddy fields in 2016 and 2017. The effects of postponing topdressing-N applications on *japonica* rice were related to variety, meteorological conditions, and soil fertility. With respect to the inbred varieties, regardless of whether panicle N was applied as a single or split application, increasing the ratio of panicle N had no effect on the yield components or dry matter accumulation of plants grown in either high- and low-fertility soils. Regarding the hybrid varieties grown in the high-fertility soil, although postponing the topdressing-N application had no effect on yield under good weather conditions (no low-temperature stress during grain-filling), a single application of 40% of the total N at the panicle initiation stage significantly decreased both the dry matter accumulation after heading and the seed-setting rate of varieties that presented long growth periods under low-temperature conditions. With respect to hybrid varieties grown in low-fertility soil, postponing the application of topdressing-N had an adverse effect on the number of effective panicles. Our results suggested that the proportion of panicle N applied to *japonica* rice should not exceed 30% in clayey paddy fields and that fertilizer management with respect to rice production should be adjusted according to soil type, soil fertility, and variety.

Keywords: *japonica* rice; postponing topdressing-N application; grain yield; soil fertility

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1. Introduction

Due to the cultivation of high-yield varieties and the development of high-yield cultivation techniques, rice yields in China have increased. In 2017, rice production in China reached 221.76 million tons, accounting for 32.1% of total grain output. N is essential for rice production and has an important effect on rice growth and yield formation [1]. However, excessive N fertilizer application and improper fertilization methods increase production costs, which not only restrict the production potential of rice but also negatively affect the environment by leaching, runoff, and volatilization [2,3]. Optimizing the application of N fertilizer to synchronize the supply of N with crop demand is of great significance for high-yield and high-efficiency rice production.

In rice production in China, N fertilizer is usually supplied via multiple applications as basal, tiller, and panicle fertilizer. Basal N is applied and mixed with soil before transplanting and tiller N is topdressed at 7–14 days after transplanting (DAT). Both basal and tiller N are used mainly to promote tillering during the early growth stage. Panicle N is topdressed at the panicle initiation (PI) stage and/or the initial spikelet differentiation (SD) stage. Panicle N is usually used to increase the number of differentiated spikelets, prevent differentiated spikelets from degeneration, increase dry matter accumulation during the middle and late growth stages, and increase the percentage of filled grains [4,5]. Generally, the basal:tiller:panicle fertilizer-N ratio is 40%–60%:20%–30%:20%–30%. The N-recovery efficiency (NRE) of panicle fertilizer is much greater than that of basal and tiller fertilizer. The NRE of basal and tiller fertilizer is approximately 10%–30%, while that of panicle fertilizer is 30%–80% [6,7]. In total, 35%–40% of applied fertilizer-N is absorbed by plants, approximately 20% to 26% is derived from panicle fertilizer, and basal and tiller fertilizers account for only approximately 7% to 10% [8–10]. Given that the NRE of panicle N is significantly greater than that of basal and tiller N, to improve the N-use efficiency (NUE) and to reduce the loss of N, postponing N applications and heavy fertilization at the reproductive stage (i.e., reducing the amounts of basal and tillering N and increasing the amount of panicle N from 20%–30% to 40%–50%) is recommended as an effective measure to increase yields and has been adopted by farmers in parts of the Yangtze River Basin and the southern rice production area in China (e.g., Lin et al. [11], Jiang et al. [12], and Zhang et al. [13]). Huang [14] suggested the ratio of panicle N should be increased from 30% to 50% to control the development of ineffective tiller and increase the productive tiller percentage. Moreover, Sun et al. [15] believed that increasing the ratio of panicle N to 40% was beneficial regarding the transport of nutrients from vegetative organs to grains during the grain-filling period.

However, some researchers have different opinions. Wu et al. [16] reported that once the percentage of panicle N exceeded 35% in double-season early rice, the changing of rice leaf color from green to yellow during ripening was delayed, which was unfavorable to grain-filling and yield increase. Lin et al. [8] reported that although increasing the ratio of panicle N from 30% to 50% increased the number of spikelets per panicle and the 1000-grain weight at a rate of 150 $kgNha^{-1}$, the yield at a rate of 300 $kgNha^{-1}$ decreased due to reductions in the seed-setting rate and the 1000-grain weight. Zhang et al. [17] reported that the effectiveness of N applied at the PI and spikelet differentiation (SD) stages on grain yield and N-use efficiency (NUE) varied substantially with varieties with different panicle sizes and suggested the application of N at the PI stage to increase the sink capacity for varieties with a small panicle size, at the SD stage to increase filling efficiency for varieties with a large panicle size, and at either at the PI stage or the SD stage for varieties with a medium panicle size. Xu et al. [18] reported that when the paddy field yield in control plots (no N fertilizer) was greater than 7000 $kgha^{-1}$, increasing the ratio of panicle N had no effect on rice grain yields. These results implied that the effects of increasing the ratio of panicle N on rice grain yield might be related to N rate, variety type, and soil fertility, but the relationship between these variables has been unclear until now.

We previously found that the NRE of N applied both before transplanting and at tillering was significantly lower than the NRE applied at PI when fertilizer-N uptake only in plants was considered; however, when the distribution of fertilizer-N in both the plants and soil was compared, 70% of the basal-^{15}N, 29% of the tillering-^{15}N, and 46% of the panicle-^{15}N was recovered in the plants and soil [7,19]. Basal fertilizer is an effective long-term fertilizer; all of the fertilizer-^{15}N taken up by plants after heading was derived from basal N, and the residual basal fertilizer-N accounted for more than 90% of the total fertilizer-N that remained in paddy soil, which was available to subsequent crops via remineralization [7]. Therefore, the low recovery efficiency of basal fertilizer-N in plants did not indicate high N loss, indicating that it is more reasonable to increase the ratio of N applied at PI by reducing the percentage of N applied at tillering while maintaining the ratio of basal N, that is, by postponing topdressing-N to increase the ratio of N applied at PI.

To determine the effect of postponing topdressing-N on the yield of different types of *japonica* rice and its relationship with soil fertility, we carried out field experiments in 2016 and 2017. Inbred *japonica* rice and hybrid *japonica* rice, which are mainly grown in the middle and lower reaches of the Yangtze River, were used as materials, and the effects of different ratios of panicle N on rice grain yield and dry matter accumulation in high- and low-fertility blue clayey paddy soils were analyzed.

2. Materials and Methods

2.1. Site Description

Field experiments were conducted at two sites at the China National Rice Research Institute (CNRRI) (120.2′ E, 30.3′ N; 11 m above sea level), Zhejiang Province, China, in 2016 and 2017. Although both sites had blue clayey paddy soils, one site presented high fertility and the other site presented low fertility. Before the plants were transplanted and fertilized, five soil cores were collected diagonally from the 0–20 cm soil layer at each site and the primary soil properties were analyzed [20]. The physical and chemical properties of both sites are shown in Table 1. The solar radiation, sunshine hours, and daily average temperatures during the rice growth periods in both 2016 and 2017 are shown in Figure 1.

Table 1. Basic chemical properties of the experimental soil (0–20 cm soil layer).

Soil Fertility	Total N (%)	Total K (%)	Total P (%)	Available N ($mg \cdot kg^{-1}$)	Available P ($mg \cdot kg^{-1}$)	Available K ($mg \cdot kg^{-1}$)	pH	Organic Matter (%)
2016								
Low fertility	0.14	1.51	0.04	25.11	7.58	54.43	7.2	0.90
High fertility	0.29	1.62	0.06	128.99	21.25	125.19	5.8	3.35
2017								
Low fertility	0.14	1.42	0.04	42.37	13.99	62.43	7.0	1.08
High fertility	0.27	1.47	0.07	143.74	23.9	154.74	5.4	3.33

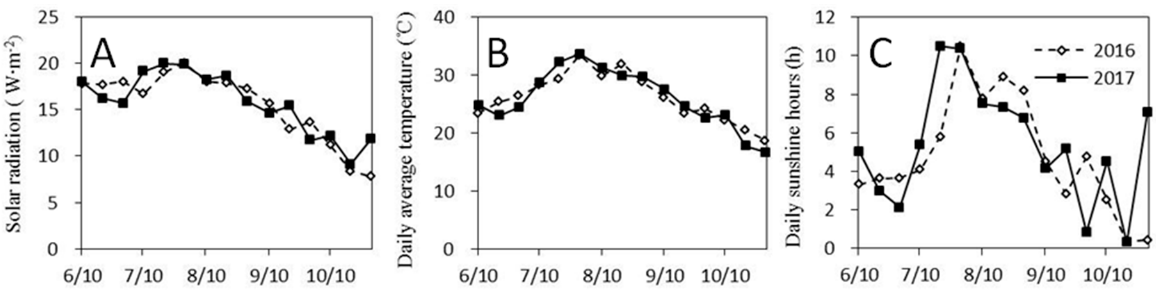

Figure 1. The mean solar radiation (**A**), temperature (**B**), and daily sunshine hours (**C**) during the growing season of rice in 2016 and 2017 at the experimental site of Hangzhou, China. The data are the means of 10 days from the transplanting of rice.

2.2. Experimental Design

At sites with high-fertility soil, the experiment was arranged in accordance with a split-plot design, with different N application ratios as the main plots and different rice varieties as the subplots. In both years, a total of 210 $kgNha^{-1}$ in the form of prilled urea was broadcast in three applications at transplanting (basal application), at tillering, and at the PI stage (26–30 days before flowering), and the different ratios of the basal:tiller:panicle fertilizer were 40%:40%:20% (F1), 40%:30%:30% (F2), and 40%:20%:40% (F3). In addition, a control treatment that received no N was implemented in 2017. In 2016, 10 *japonica* varieties were grown, including 6 inbred *japonica* varieties (C1–C6) and 4 hybrid *japonica* varieties (H1–H4). In 2017, 8 *japonica* varieties were grown, including 4 inbred *japonica* varieties (C1–C4) and 4 hybrid *japonica* varieties (H1–H4) (Table 2). All of these cultivars are widely planted in Southern China. The experiment was replicated three times, and the size of each subplot was 20 m^2.

Table 2. *Japonica* varieties used in the experiment.

	Varieties	Types
C1	Nangeng46	Inbred variety
C2	Nangeng5055	Inbred variety
C3	Ninggeng4	Inbred variety
C4	Jia58	Inbred variety
C5	Jiahe218	Inbred variety
C6	Ninggeng1	Inbred variety
H1	Yongyou1538	Hybrid variety
H2	Yongyou538	Hybrid variety
H3	Chunyou84	Hybrid variety
H4	Yongyou12	Hybrid variety

At sites with low-fertility soil, the experiment was also arranged in accordance with a split-plot design, with N application ratios as the main plots and rice varieties as the subplots. In order to avoid possible adverse effects of a large amount of panicle fertilizer applied at one time on plant growth, the panicle N was split and applied twice at 26–30 days and 5–7 days before flowering, when it accounted for 30% or 40% of total N. Thus, according to the ratios of N applied before transplanting, at tillering, and at 26–30 days and 5–7 days before flowering, a total of 6 N treatments were designed: 40%:40%:20%:0% (T1), 40%:30%:20%:10% (T2), 40%:30%:30%:0% (T3), 40%:20%:20%:20% (T4), 40%:20%:30%:10% (T5), and 40%:20%:40%:0% (T6). In addition, a control treatment with no N (T0) was implemented in both years. Among the N treatments, the percentage of panicle fertilizer of T2 and T3 accounted for 30% of the total N application, and that of T4, T5, and T6 accounted for 40% of the total N application. The inbred *japonica* variety Nangeng 5055 (C2) and the hybrid *japonica* rice variety Yongyou 1538 (H1) were used as materials in this experiment. The experiment was replicated three times, and the size of each subplot size was 12 m^2.

Rice was sown on 25 May and 20 May and transplanted on 19 June and 14 June in 2016 and 2017, respectively. The transplanting density for both years was 25.0 cm $\times$ 20.0 cm, with two plants transplanted per hill. In all treatments, the basal urea was broadcast and incorporated into the paddy soil 1 day before transplanting, the tillering urea was topdressed 10 days after transplanting (DAT), and the panicle urea was topdressed once (26–30 days before flowering) in high-fertility soil and twice (26–30 days and 5–7 days before flowering) in low-fertility soil. Potassium was applied in the form of KCl in two applications at a rate of 157 kgKha^{-1}, with 50% applied as basal fertilizer and 50% applied as topdressing at PI. Phosphorus was broadcast as a basal fertilizer in the form of calcium superphosphate at a rate of 43 kgPha^{-1}. To avoid cross-fertilization, each subplot was coated with black plastic film and was fertilized and drained separately. The field was flooded after transplanting, and a depth of 1–4 cm of flooding water was maintained until the end of the tillering period. Afterward, the water was drained, and the plots remained nonflooded for 7–10 days to control unproductive tillers. The field was reflooded before the panicle fertilizer application, and a water depth of 1–4 cm was again maintained until mid-grain-filling. Insects were intensively controlled by chemicals to avoid biomass and yield losses.

2.3. Sampling and Measurements

At heading and maturity, the number of effective panicles of plants of 20 hills was continually assessed in each subplot, and the average number of effective panicles was calculated. Plants of six hills were sampled according to the average number of effective panicles from each subplot. All sampled plants were divided into panicles and straw; the panicles of the plants sampled at maturity were hand-threshed and filled spikelets were separated from unfilled spikelets by submerging them in tap water. The dry weight of the panicles and straw was determined after oven drying at 70 °C for 48 h until a constant weight was achieved. The plant dry weight at heading and maturity was calculated as the sum of the weights of all the parts, and the dry weight accumulation during the grain-filling phase was calculated as the difference in total aboveground dry weight between heading and maturity. Three subsamples (20 g) of filled spikelets were collected and counted to determine the grain weight (20 divided by the number of filled spikelets), and the number of filled spikelets was calculated as the total dry weight of the filled spikelets divided by the grain weight. All unfilled spikelets and the number of total spikelets (filled and unfilled) were calculated. The aboveground total dry weight at maturity included the total dry matter of the straw, rachises, and filled and unfilled spikelets. The number of spikelets per panicle (the ratio of the total spikelet number to the panicle number) and the grain-filling percentage (the ratio of the filled spikelet number to the total spikelet number) were subsequently calculated. The grain yield was determined from 100 hills in each subplot and adjusted to the standard moisture content of 14.0%.

2.4. Statistical Analysis

The data generated from the experiments were subjected to SAS for Windows statistical software (Statistical Analysis System, version 9.2, SAS Institute, Cary, NC, USA); the data for 2016 and 2017 were analyzed separately. A two factorial split-plot variance analysis was conducted for all of the abovementioned parameters from three replicates at harvest. Yield and dry weight comparisons were made among the various combinations of N rates and varieties via Duncan's multiple range test; a p-value of <0.05 was considered significantly different.

3. Results

3.1. Effects of Postponing Topdressing-N on the Rice Yield and Dry Matter Accumulation in High-Fertility Soil

3.1.1. Inbred *japonica* Rice

When inbred *japonica* rice were grown in high-fertility soil, the grain yield of the inbred *japonica* varieties under different N treatments in 2016 ranged from 6675 to 9409 kgha^{-1}, which was significantly greater than the yield in 2017 (5889–7563 kgha^{-1}). There were significant differences in yield among the rice varieties. In both years, the yield of C4 was the greatest, whereas that of C3 was the lowest. However, there was little difference in grain yield among the different N treatments used for the different inbred varieties. No effects of postponing topdressing-N on the 1000-grain weight, effective panicle number, grain number per panicle, or seed-setting rate were observed (Table 3).

The dry matter accumulation of inbred *japonica* rice in 2016 at heading and maturity was 8455–11,352 kgha^{-1} and 13978–16,871 kgha^{-1}, respectively (Figure 2). The dry matter accumulation in 2017 was much lower and was only 6610–10,685 kgha^{-1} at the heading stage and 121,43–15,332 kgha^{-1} at the maturity stage. However, although there were differences between years, no significant differences in dry matter accumulation among the N treatments were observed in either year for any of the inbred varieties.

3.1.2. Hybrid *japonica* Rice

In high-fertility soil, the grain yield of the hybrid *japonica* varieties under the different N treatments ranged from 10,708 to 11,407 kgha^{-1} in 2016, which was significantly greater than the grain yield in 2017 (8694–10,231 kgha^{-1}) (Table 4). There were no differences in grain yield between varieties and N treatments in 2016; however, significant differences in yields among varieties were detected in 2017, with the grain yield of H1 being the greatest. In 2017, the interaction between variety and N treatment was significant for grain yield, and the yield of H3 and H4 in F3 was significantly lower than that of the other treatments.

Table 3. Grain yield and yield components of inbred *japonica* varieties grown in high-fertility soil in 2016 and 2017.

Year	Varieties	Treatments	Yield (kgha^{-1})	Effective Panicle Number (10^4 ha^{-1})	Spikelets per Panicle	1000-Grain Weight (g)	Seed-Setting Rate (%)
2016	C1	F1	8751 ^{a}	281.1 ^{a}	137.5 ^{a}	25.3 ^{a}	88.7 ^{a}
		F2	8950 ^{a}	290.3 ^{a}	132.4 ^{a}	25.8 ^{a}	91.3 ^{a}
		F3	8913 ^{a}	289.7 ^{a}	139.5 ^{a}	25.4 ^{a}	90.6 ^{a}
	C2	F1	8135 ^{a}	292.1 ^{a}	135.9 ^{a}	23.6 ^{a}	90.1 ^{a}
		F2	8317 ^{a}	298.1 ^{a}	141.5 ^{a}	23.6 ^{a}	86.8 ^{a}
		F3	7922 ^{a}	292.5 ^{a}	142.8 ^{a}	23.5 ^{a}	87.4 ^{a}
	C3	F1	6675 ^{a}	262.8 ^{a}	168.0 ^{a}	24.2 ^{a}	68.4 ^{a}
		F2	6776 ^{a}	271.0 ^{a}	166.6 ^{a}	23.8 ^{a}	70.0 ^{a}
		F3	7185 ^{a}	254.0 ^{a}	185.2 ^{a}	23.4 ^{a}	69.2 ^{a}
	C4	F1	8454 ^{a}	292.9 ^{a}	134.6 ^{a}	23.2 ^{a}	87.6 ^{a}
		F2	8936 ^{a}	315.1 ^{a}	129.8 ^{a}	23.1 ^{a}	92.7 ^{a}
		F3	9409 ^{a}	305.3 ^{a}	139.0 ^{a}	22.9 ^{a}	90.6 ^{a}
	C5	F1	8996 ^{a}	239.3 ^{a}	145.9 ^{a}	27.7 ^{a}	92.2 ^{a}
		F2	9162 ^{a}	256.0 ^{a}	145.7 ^{a}	27.8 ^{a}	89.3 ^{a}
		F3	8495 ^{a}	248.9 ^{a}	145.0 ^{a}	27.5 ^{a}	94.0 ^{a}
	C6	F1	8806 ^{a}	292.7 ^{a}	128.6 ^{a}	25.7 ^{a}	92.3 ^{a}
		F2	8634 ^{a}	308.6 ^{a}	121.5 ^{a}	26.2 ^{a}	92.8 ^{a}
		F3	8611 ^{a}	299.6 ^{a}	122.6 ^{a}	25.7 ^{a}	90.4 ^{a}
2017	C1	F0	5634 ^{b}	201.6 ^{b}	124.9 ^{b}	25.6 ^{a}	89.5 ^{a}
		F1	7367 ^{a}	251.3 ^{a}	144.7 ^{a}	26.6 ^{a}	83.1 ^{b}
		F2	7563 ^{a}	259.6 ^{a}	138.0 ^{a}	26.3 ^{a}	78.5 ^{b}
		F3	7370 ^{a}	251.5 ^{a}	138.8 ^{a}	26.0 ^{a}	85.0 ^{b}
	C2	F0	5672 ^{b}	231.5 ^{b}	91.9 ^{b}	23.7 ^{a}	88.2 ^{a}
		F1	7207 ^{a}	284.7 ^{a}	121.0 ^{a}	23.8 ^{a}	88.6 ^{a}
		F2	7465 ^{a}	269.6 ^{a}	118.5 ^{a}	24.6 ^{a}	89.2 ^{a}
		F3	6891 ^{a}	284.6 ^{a}	132.0 ^{a}	24.1 ^{a}	84.1 ^{a}
	C3	F0	4159 ^{b}	208.8 ^{b}	188.8 ^{a}	24.5 ^{a}	85.7 ^{a}
		F1	5890 ^{a}	240.3 ^{a}	148.0 ^{b}	24.4 ^{a}	66.3 ^{b}
		F2	6131 ^{a}	244.6 ^{a}	165.9 ^{b}	24.5 ^{a}	73.1 ^{b}
		F3	5764 ^{a}	257.4 ^{a}	170.0 ^{b}	24.6 ^{a}	69.3 ^{b}
	C4	F0	6519 ^{b}	213.5 ^{b}	143.5 ^{a}	25.6 ^{a}	92.0 ^{a}
		F1	7471 ^{a}	265.9 ^{a}	129.0 ^{b}	25.8 ^{a}	91.5 ^{a}
		F2	7505 ^{a}	264.6 ^{a}	127.9 ^{b}	26.1 ^{a}	94.7 ^{a}
		F3	7441 ^{a}	258.6 ^{a}	133.4 ^{b}	26.1 ^{a}	92.4 ^{a}

The means were obtained from three replications. Different letters in the same column of the same variety indicate significant differences at $p < 0.05$.

Table 4. Grain yield of hybrid *japonica* rice grown in high-fertility soil in 2016 and 2017.

Varieties	Treatments	Yield	
		2016	2017
H1	F0	/	7773 ^{b}
	F1	11,207 ^{a}	10,138 ^{a}
	F2	10,779 ^{a}	10,231 ^{a}
	F3	10,757 ^{a}	9551 ^{a}
H2	F0	/	7300 ^{b}
	F1	11,407 ^{a}	9567 ^{a}
	F2	10,810 ^{a}	9347 ^{a}
	F3	10,998 ^{a}	9412 ^{a}
H3	F0	/	7517 ^{b}
	F1	10,581 ^{a}	9167 ^{a}
	F2	10,080 ^{a}	9100 ^{a}
	F3	10,355 ^{a}	8694 ^{b}
H4	F0	/	7411 ^{c}
	F1	10,786 ^{a}	9164 ^{a}
	F2	10,708 ^{a}	8933 ^{b}
	F3	10,370 ^{a}	8860 ^{b}
Analysis of variance			
	Variety (V)	ns	*
	Treatment (T)	ns	ns
	V × T	ns	*

The means were obtained from three replications. Different letters in the same column of the same variety indicate significant differences at $p < 0.05$; ns and * indicate not significant and significance at $p = 0.05$, respectively.

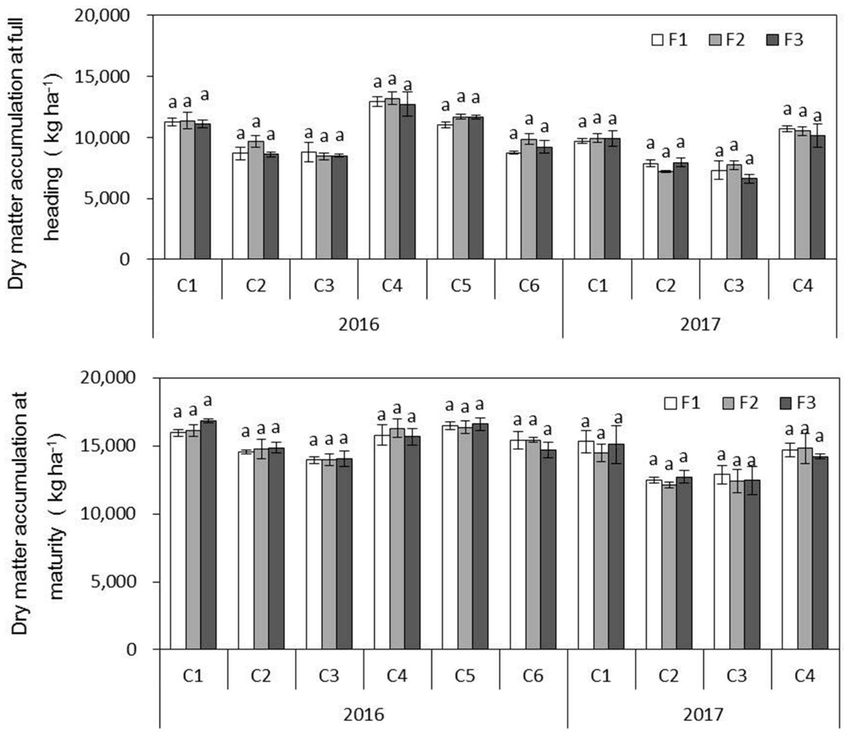

Figure 2. Dry matter accumulation at heading and maturity of inbred varieties grown in high-fertility soil in 2016 and 2017. The vertical bars represent the standard errors of the means, and the different letters above the column of the same variety indicate significant differences at $p < 0.05$.

To further analyze the variation in yield between varieties and years caused by postponing topdressing-N, we classified all the treatments in 2016 and 2017 into two categories according to the changes in grain yield, namely, no significant difference in yield between N fertilizer treatments (no impact) and significantly reduced yields when 40% of the N was applied at PI (yield reduction). H1–H4 in 2016 and H1 and H2 in 2017 were classified as the no-impact group, while H3 and H4 in 2017 were classified as the reduction group. The yield components of the above two groups are shown in Table 5. In the no-impact group, although there were significant differences in the number of spikelets per panicle, the 1000-grain weight, the seed-setting rate, and the number of effective panicles among varieties and years, no significant differences were detected between the N treatments. However, in the yield-reduction group, there was a significant difference in the seed-setting rate among the N treatments. The seed-setting rate decreased with increasing panicle fertilizer, and the value of F3 was significantly lower than that of F1 and in H3 (by 9.2%) and H4 (by 10.2%). Correlation analysis revealed that the seed-setting rate was significantly negatively correlated with grain yield in both H3 ($r = -0.698$, $p < 0.05$, $n = 9$) and H4 ($r = -0.725$, $p < 0.05$, $n = 9$).

In the high-fertility soil, the dry matter accumulation of the hybrid *japonica* varieties ranged from 11,274 to 16,256 $kgha^{-1}$ at full heading and from 18,268 to 21,972 $kgha^{-1}$ at maturity in 2016; no significant differences in these values were detected among N treatments (Figure 3). In 2017, the difference in dry matter accumulation at full heading among the N treatments was significant, except for H1. The greatest dry matter accumulation was observed in F2, which was 12,659, 12,916, and 13,542 $kgha^{-1}$ in H2, H3, and H4, respectively. At maturity, although no obvious difference in dry matter accumulation was detected among the treatments in hybrid varieties H1 and H2, the lowest significant values were observed in F3 in hybrid varieties H3 and H4, which were 14.3% and 10.1% lower than that of F2, respectively.

Table 5. Yield components of hybrid *japonica* rice grown in high-fertility soil in 2016 and 2017.

Year and Variety	Treatments	Effective Panicles ($10^4 \cdot ha^{-1}$)	Spikelets per Panicle	Seed-Setting Rate (%)	1000-Grain Weight (g)
Non-impact					
2016H1	F1	214.3 ^{a}	285.4 ^{a}	84.7 ^{a}	21.1 ^{a}
	F2	212.1 ^{a}	264.4 ^{a}	83.6 ^{a}	21.6 ^{a}
	F3	212.5 ^{a}	297.3 ^{a}	81.6 ^{a}	21.2 ^{a}
2016H2	F1	208.3 ^{a}	307.8 ^{a}	85.6 ^{a}	20.6 ^{a}
	F2	208.1 ^{a}	304.7 ^{a}	81.6 ^{a}	20.4 ^{a}
	F3	213.8 ^{a}	313.2 ^{a}	81.6 ^{a}	20.3 ^{a}
2016H3	F1	215.8 ^{a}	230.5 ^{a}	82.7 ^{a}	23.8 ^{a}
	F2	223.8 ^{a}	257.9 ^{a}	79.3 ^{b}	23.7 ^{a}
	F3	207.5 ^{a}	273.1 ^{a}	80.5 ^{ab}	23.5 ^{a}
2016H4	F1	201.0 ^{a}	358.0 ^{a}	70.8 ^{a}	21.9 ^{a}
	F2	199.3 ^{a}	355.3 ^{a}	73.4 ^{a}	21.5 ^{a}
	F3	194.2 ^{a}	368.7 ^{a}	74.1 ^{a}	21.3 ^{a}
2017H1	F1	196.5 ^{a}	277.0 ^{a}	81.8 ^{a}	21.9 ^{a}
	F2	190.1 ^{a}	315.8 ^{a}	79.0 ^{a}	21.8 ^{a}
	F3	198.0 ^{a}	272.9 ^{a}	79.0 ^{a}	21.6 ^{a}
2017H2	F1	184.7 ^{a}	320.9 ^{a}	75.7 ^{a}	22.0 ^{a}
	F2	183.5 ^{a}	340.1 ^{a}	79.2 ^{a}	22.1 ^{a}
	F3	179.5 ^{a}	316.9 ^{a}	78.3 ^{a}	22.3 ^{a}
		Analysis of variance			
Year		**	ns	ns	ns
Variety		**	**	**	**
Treatment		ns	ns	ns	ns
Yield-reduction					
2017H3	F1	199.0 ^{a}	235.9 ^{a}	87.3 ^{a}	25.5 ^{a}
	F2	196.8 ^{a}	242.7 ^{a}	85.1 ^{a}	25.0 ^{a}
	F3	188.0 ^{a}	230.1 ^{a}	79.3 ^{b}	25.4 ^{a}
2017H4	F1	168.8 ^{a}	326.9 ^{b}	80.0 ^{a}	22.6 ^{a}
	F2	169.4 ^{a}	361.8 ^{a}	74.3 ^{b}	22.5 ^{a}
	F3	168.6 ^{a}	334.1 ^{ab}	71.8 ^{c}	22.7 ^{a}
		Analysis of variance			
Variety		**	**	**	**
Treatment		ns	ns	*	ns

The means were obtained from three replications. Different letters in the same column of the same variety indicate significant differences at $p < 0.05$; ns and ** indicate not significant and significance at $p = 0.01$, respectively.

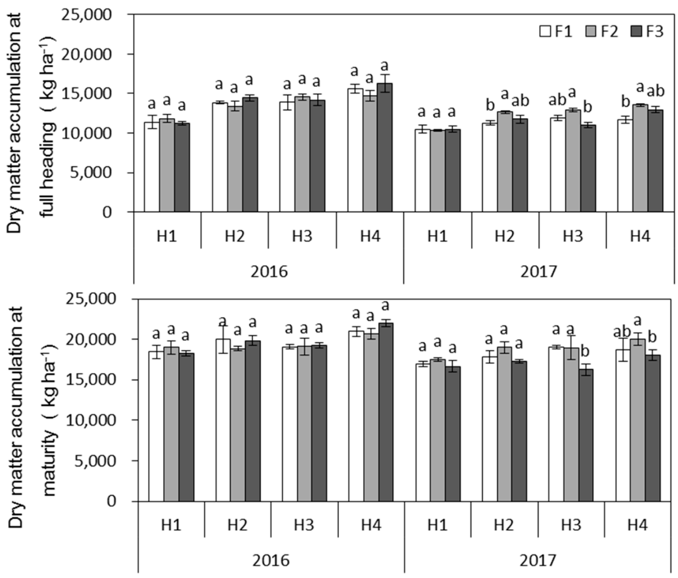

Figure 3. Dry matter accumulation at heading and maturity of hybrid rice grown in high-fertility soil in 2016 and 2017. The means were obtained from three replications and the vertical bars represent the standard errors of the means. Different letters above the column of the same variety indicate significant differences at $p < 0.05$.

We further compared the dry matter accumulation during the grain-filling period. To make the data of different varieties and years comparable, the dry matter accumulation during the grain-filling period of F1 for each variety was set to 100, and the F2 and F3 treatments were converted into corresponding percentages. Analysis of variance revealed no significant differences in dry matter accumulation during the grain-filling period among the N treatments in the no-impact group, while a significant decrease in dry matter accumulation during the grain-filling period was detected with an increase in panicle N in the yield-reduction group. Compared with that of F1, the accumulation values of F2 and F3 were 10.7% and 26.5% lower, respectively (Figure 4).

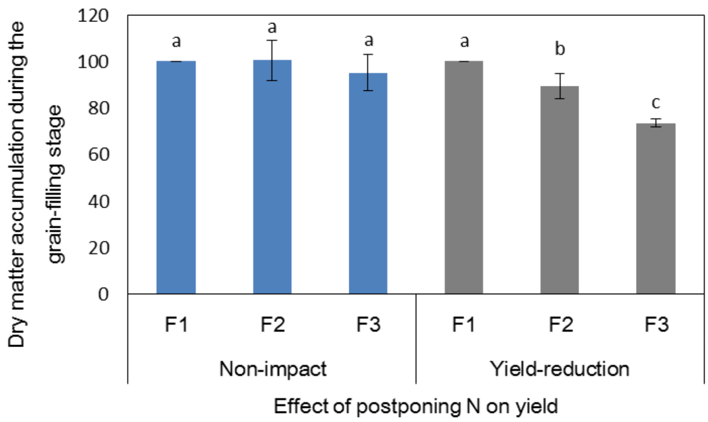

Figure 4. Dry matter accumulation during the grain-filling of varieties that responded differently to postponed N application. Under the assumption that the dry matter accumulation of F1 is 100, the values of F1 compared with those of F2 and F3 are shown. The vertical bars represent the standard errors of the means. Different letters above the column of the same variety indicate significant differences at $p < 0.05$.

3.2. *Effects of Postponing Topdressing-N on the Grain Yield and Dry Matter Accumulation in Low-Fertility Soil*

3.2.1. Inbred *japonica* Rice

Similar to that which occurred for plant growth in the high-fertility soil, inbred variety C2 grown in the low-fertility soil presented a greater grain yield and dry matter accumulation in 2016 than in 2017; no significant difference was detected between the treatments in which 20% (T1), 30% (T3), and 40% (T6) of fertilizer-N was applied in a single application at PI (Table 6). To avoid possible adverse effects of a large amount of panicle fertilizer applied at one time on plant growth, when the N applied at PI constituted 30% or more, additional applications were made such that the remaining N was applied at leaf ages of 3.5 (26–30 days before flowering, PI) and 1.0 (5–7 days before flowering). When 30% and 40% of total N was applied as panicle fertilizer, the grain yield and dry matter accumulation at both heading and maturity in response to the split-application treatments (T2, T4, T5) were similar to those observed in response to the single-application treatments (T3, T6). With the exception of the 1000-grain weight in T3, which was significantly lower than T1 in 2016, no obvious differences in yield components, including the number of effective panicles, spikelets per panicle, 1000-grain weight, seed-setting rate, and dry matter accumulation, between the other treatments were detected at heading or at maturity in 2016 and 2017 (Table 4).

Table 6. Dry matter accumulation, grain yield, and yield components of inbred *japonica* variety Nangen 5055 grown in low-fertility soil in 2016 and 2017.

Treatments	Dry Matter Accumulation		Yield ($kg{\cdot}ha^{-1}$)	Yield Components			
	At Heading ($kgha^{-1}$)	At Maturity ($kgha^{-1}$)		Effective Panicles ($10^4{\cdot}ha^{-1}$)	Spikelets per Panicle	1000-Grain Weight (g)	Seed-Setting Rate (%)
2016							
T0	2679 ^{b}	4849 ^{b}	1586 ^{b}	116.2 ^{b}	74.3 ^{b}	24.1 ^{b}	60.0 ^{b}
T1	7507 ^{a}	9701 ^{a}	4825 ^{a}	224.4 ^{a}	119.4 ^{a}	25.6 ^{a}	70.4 ^{a}
T2	7594 ^{a}	9647 ^{a}	4782 ^{a}	220.1 ^{a}	124.4 ^{a}	25.2 ^{ab}	69.4 ^{a}
T3	7451 ^{a}	9275 ^{a}	4638 ^{a}	218.7 ^{a}	117.6 ^{a}	24.4 ^{b}	73.9 ^{a}
T4	7600 ^{a}	8926 ^{a}	4342 ^{a}	215.2 ^{a}	111.0 ^{a}	25.2 ^{ab}	72.2 ^{a}
T5	7511 ^{a}	9430 ^{a}	4468 ^{a}	216.0 ^{a}	115.8 ^{a}	25.1 ^{ab}	71.1 ^{a}
T6	7707 ^{a}	8703 ^{a}	4473 ^{a}	214.3 ^{a}	113.3 ^{a}	24.7 ^{ab}	74.1 ^{a}
2017							
T0	1287 ^{b}	2357 ^{b}	715 ^{b}	53.2 ^{b}	81.6 ^{b}	22.8 ^{a}	73.8 ^{b}
T1	3197 ^{a}	5485 ^{a}	2538 ^{a}	129.5 ^{a}	104.4 ^{a}	23.0 ^{a}	85.8 ^{a}
T2	3218 ^{a}	5076 ^{a}	2286 ^{a}	127.9 ^{a}	95.6 ^{a}	23.3 ^{a}	82.0 ^{a}
T3	3737 ^{a}	5106 ^{a}	2387 ^{a}	128.9 ^{a}	96.7 ^{a}	23.2 ^{a}	86.3 ^{a}
T4	3205 ^{a}	5016 ^{a}	2168 ^{a}	130.8 ^{a}	87.6 ^{a}	23.5 ^{a}	82.5 ^{a}
T5	2867 ^{a}	5075 ^{a}	2410 ^{a}	129.4 ^{a}	100.9 ^{a}	23.3 ^{a}	82.0 ^{a}
T6	2742 ^{a}	4860 ^{a}	2326 ^{a}	128.5 ^{a}	95.2 ^{a}	23.2 ^{a}	86.4 ^{a}

The means were obtained from three replications. Different letters in the same column indicate significant differences at $p < 0.05$.

3.2.2. Hybrid *japonica* Rice

The yield of hybrid rice grown in low-fertility soil was also significantly different between 2016 and 2017 (Table 7). In 2016, the grain yield in H1 under different N treatments was in the range of 9583–10,716 $kgha^{-1}$, while it was only 5012–7101 $kgha^{-1}$ in 2017. The average numbers of effective panicles, spikelets per panicle, and 1000-grain weight in 2016 were 32.1%, 13.4%, and 8.8% greater than those in 2017, respectively. In low-fertility soil, when panicle N was supplied as a single application at PI, the yield in H1 decreased with increasing percentage of panicle fertilizer, and the yields of T6 (where 40% of the N was supplied as a single application at PI) were significantly lower than T1 (where 20% of the N was supplied as a single application at PI) by 10.6% and 29.4% in 2016 and 2017, respectively. The differences between N treatments were more obvious in 2017 than in 2016.

Table 7. Grain yield and yield components of hybrid *japonica* variety Yongyou 1538 grown in low-fertility soil in 2016 and 2017.

Year	Treats	Yield ($kgha^{-1}$)	Effective Panicle ($10^4{\cdot}ha^{-1}$)	Spikelets per Panicle	1000-Grain Weight (g)	Seed-Setting Rate (%)
2016	T0	4660 ^{c}	98.8 ^{c}	295.7 ^{b}	21.5 ^{c}	86.7 ^{a}
	T1	10717 ^{a}	186.2 ^{a}	344.0 ^{a}	22.7 ^{a}	86.9 ^{a}
	T2	10497 ^{ab}	171.0 ^{b}	372.3 ^{a}	22.3 ^{ab}	84.9 ^{a}
	T3	10553 ^{ab}	173.0 ^{b}	359.9 ^{a}	22.5 ^{ab}	86.4 ^{a}
	T4	10625 ^{ab}	172.3 ^{b}	351.0 ^{a}	22.2 ^{ab}	88.4 ^{a}
	T5	9970 ^{ab}	170.6 ^{b}	343.8 ^{a}	22.3 ^{ab}	87.1 ^{a}
	T6	9583 ^{b}	168.8 ^{b}	333.6 ^{b}	22.0 ^{b}	86.3 ^{a}
2017	T0	2189 ^{c}	44.9 ^{c}	298.2 ^{a}	20.1 ^{a}	75.9 ^{c}
	T1	7101 ^{a}	132.2 ^{a}	293.2 ^{a}	20.0 ^{a}	90.2 ^{a}
	T2	6366 ^{b}	115.9 ^{b}	314.7 ^{a}	20.7 ^{a}	86.6 ^{b}
	T3	6338 ^{b}	116.6 ^{b}	307.4 ^{a}	20.1 ^{a}	88.0 ^{b}
	T4	6262 ^{b}	116.7 ^{b}	298.0 ^{a}	20.7 ^{a}	87.4 ^{b}
	T5	5726 ^{bc}	111.5 ^{b}	299.3 ^{a}	20.4 ^{a}	84.0 ^{b}
	T6	5012 ^{c}	114.5 ^{b}	310.2 ^{a}	20.3 ^{a}	76.4 ^{c}

The means were obtained from three replications. Different letters in the same column indicate significant differences at $p < 0.05$.

Additional comparisons of single and split applications of panicle N were made. When 30% of the N was applied as panicle fertilizer, no significant differences in yield between single (T3) and split (T2) applications were detected. When the percentage of panicle N reached 40%, the yield of

T4 was greater than that of both T5 and T6, and a significantly lower value was observed in T6 in 2017, indicating that single applications of 40% total N at PI in low-fertility soil had adverse effects on the grain yield of hybrid rice. Analysis of the yield components revealed that when N fertilizer applied at tillering decreased from 40% (T1) to 30% (T2, T3), the number of effective panicles of rice grown on low-fertility soil significantly decreased in both years, while the number of spikelets per panicle increased. However, further reduction in the tiller fertilizer ratio to 20% and an increase in the panicle N ratio to 40% had little effect on panicle number and grain number per panicle, with the exception that the number of grains per panicle in T6 was significantly lower than T3 in 2016. Although postponing topdressing-N had no effect on the seed-setting rate in 2016, it decreased the seed-setting rate in 2017, especially when 40% of the N was supplied as a single application, where the value of T6 (single application) was 15.3% lower than T1 and 10.8% lower than the average values of T4 and T5, both of which involved split applications.

In the low-fertility soil, postponing the topdressing-N had an adverse effect on the dry matter accumulation before heading (Table 8). When the ratio of N applied at tillering was reduced from 40% to 30%, consequently increasing the ratio applied at PI from 20% to 30%, the dry matter accumulation at heading significantly decreased by 7.6% and 5.0% in 2016 and 2017, respectively. Further decreases in this value were observed in 2017 when the ratio of tillering N was reduced to 20% (T6). Also in 2017, T6 presented significantly lower dry matter accumulation at heading than the other treatments. There was no significant difference in dry matter accumulation during the grain-filling period among T1–T5 in 2016 and among T1–T4 in 2017, indicating that single or split applications of panicle fertilizer did not affect the accumulation of dry matter during the grain-filing period when the amount of panicle fertilizer constituted 30% or less,. However, when the ratio of N applied at PI increased to 40%, the values resulting from single applications (T6) were significantly lower than those resulting from split applications (T4, T5). The dry matter accumulation at maturity was greatest at T1, and T6 presented the lowest value from both years.

Table 8. Dry matter accumulation of inbred *japonica* variety Yongyou 1538 grown in low-fertility soil in 2016 and 2017.

Treatments	At Heading (kgha^{-1})		During Grain-filling (kgha^{-1})		At Maturity (kgha^{-1})	
	2016	2017	2016	2017	2016	2017
T1	12,071 ^{a}	7651 ^{a}	6355 ^{a}	5313 ^{a}	18,426 ^{a}	12,964 ^{a}
T2	11,155 ^{b}	7271 ^{b}	6624 ^{a}	4898 ^{a}	17,779 ^{ab}	12,269 ^{ab}
T3	10,920 ^{b}	7037 ^{b}	6762 ^{a}	4877 ^{a}	17,681 ^{ab}	11,914 ^{b}
T4	10,522 ^{b}	6512 ^{cd}	7229 ^{a}	4950 ^{a}	17,751 ^{ab}	11,452 ^{bc}
T5	10,742 ^{b}	6957 ^{bc}	6227 ^{a}	3844 ^{b}	16,969 ^{ab}	10,801 ^{c}
T6	11,501 ^{b}	6150 ^{d}	5171 ^{b}	3500 ^{b}	16,223 ^{b}	9650 ^{d}

The means were obtained from three replications. Different letters in the same column indicate significant differences at $p < 0.05$.

4. Discussion

In this study, there was a significant difference in grain yield and dry matter accumulation between the years in both the high-fertility and low- fertility soils, with significantly lower values being detected in 2017 compared with 2016. This difference was likely due to the worse light and temperature conditions during the critical rice growth period in 2017. For example, the daily average temperature, solar radiation, and sunshine hours for two weeks after transplanting in 2016 were 26.1 °C, 18.2 Wm^{-2}, and 3.8 h, respectively, and 23.9 °C, 16.5 Wm^{-2}, and 2.8 h in 2017, respectively. Previous research showed that sunshine, temperature, water, and N affect tiller development [21,22]. Low temperature, low light intensity, and short sunshine duration after transplanting in 2017 delayed tiller development, and the number of effective panicles of the inbred and hybrid *japonica* rice decreased from 2016 to 2017 by 18.6% and 17.5%, respectively. In addition, at the beginning of the panicle differentiation stage (2–8 August), the daily average temperature and the maximum and minimum daily temperatures in 2017 were 31.8 °C, 37.9 °C, and 28.4 °C, respectively, which were obviously greater than the 29.8 °C, 35.1 °C, and 26.2 °C values in 2016. It is well-known that the number of grains per panicle is determined at the PI stage, which is one of the most sensitive stages to high temperature and heat [23]. Rice spikelets are prone to dysplasia when the average daily temperature is greater than 30 °C and when the daily maximum temperature reaches 35 °C [24]. The high temperature at PI in 2017 in our experiment had a negative impact on the development of spikelets and resulted in an 8.2% and 5.6% decrease in the average grains per panicle of the inbred and hybrid *japonica* varieties, respectively. Furthermore, the temperature decreased abruptly during the late grain-filling period in 2017 (12–22 October), and the daily average temperature and the daily minimum temperature in 2017 were 17.5 °C and 15.6 °C, respectively, which were significantly lower than the corresponding values (20.7 °C and 19.3 °C, respectively) in 2016. As the numbers of effective panicles and grains per panicle in 2017 were lower than those in 2016, the yield in 2017 was lower than that in 2016.

Berge et al. [25] recommended that frequent, small doses of fertilizer be applied to synchronize with crop demand. In transplanted rice production systems, N fertilizer is applied several times, for example, as a basal fertilizer (applied before transplanting), revival (turning green) fertilizer (applied within one week after transplanting), tillering fertilizer, and panicle fertilizer. Tillering and panicle fertilizer can be topdressed more than once, i.e., at the initial and middle tillering/booting stages or even at or after heading [26]. However, given increased labor costs and findings describing that more than three divided fertilizer-N applications had only small effects on grain yield, N fertilizer is usually applied to paddy fields three times, namely, before transplanting, at initial tillering, and at PI. Previous studies have clarified the function of N applied during different growth periods [27,28]. The major roles of basal and tillering fertilizer-N are to stimulate the production of tillers and to promote early growth [27,28]. It is believed that the leaves on the main culm emerge successively at definite intervals and that the individual leaves on the main culm develop simultaneously with certain tillers [29]. A suitable N level in the plant shortens the leafing interval of the main culm and causes secondary, tertiary, and quaternary tillers to appear ahead of the synchronous pattern; however, when the N level decreases, the leafing interval becomes longer, and a delay in tiller development results [30]. Therefore, the premise of "postponing N application and heavy fertilization at the booting stage" is that N supply is sufficient during the early growth stage; otherwise, it is easy to obtain insufficient numbers of effective panicles and reduced yields. The view of "postponing N application" management is agreed upon and supported by many researchers in China. Zhang et al. [31] reported that postponing the application of N increased the panicle N, consequently constituting 50% of the total N to prevent excessive growth of the tillers and leaves at the vegetative stage, while both the dry matter accumulation during the grain-filling period and grain yield increased. Similar results were also reported by Lin et al. (2005), Li et al. (2010), and Sun et al. (2017). However, these studies only used limited varieties as materials and ignored the effects of soil N supply capacity on plant N demand.

It is well-known that a significant portion of N uptake by rice plants originates from soil N, and that the yield of rice growing in high-fertility soil is usually greater than that growing in low-fertility soil [13,32]. For example, Zhang et al. [13] reported that more than 60% of N in plant tissue was derived from soil N supplied by N which was applied at rates ranging from 240–300 kgha^{-1}; [33] reported that 80% of the N within a crop was derived from soil N supplied by N which was applied at a rate of 140 kgha^{-1}. Using the mid-season *indica* hybrid rice Chuanxiang-you 9839 as a material, Xu et al. [18] reported that the effect of an increased ratio of panicle N on rice grain yield was related to the basic fertility of the soil. If the yield of the soil not fertilized with N was more than 7000 kgha^{-1}, postponing the N application did not increase the yield, and even reduced the yield when 40% of the total N was applied at PI.

In this study, six inbred and four hybrid *japonica* rice varieties were used as materials, and the effects of postponing topdressing-N in both high-fertility and low-fertility blue clayey paddy soils were analyzed. In contrast to previous studies, our experiment showed that the effects of postponing topdressing-N on rice yield were related to variety, meteorological conditions, and soil fertility. Three general conclusions are outlined below.

(1) In inbred *japonica* rice, increasing the ratio of panicle N had no effect on grain yield or dry matter accumulation in both high-fertility and low-fertility soils, although there were differences between years. The yield components in the different treatments in the same year were similar, as was the dry matter accumulation.

(2) With respect to hybrid *japonica* rice grown in high-fertility soil, increasing the ratio of panicle N had no effect on the number of effective panicles, the number of spikelets per panicle, or the 1000-grain weight in either year, while the effect on the seed-setting rate differed between 2016 and 2017. In 2016, which presented good temperature conditions during the grain-filling period, there was no significant difference in seed-setting rate between the treatments for any variety; however, in 2017, during which the temperature sharply declined in mid-October, the seed-setting rate of only H1 and H2 remained unchanged, while that of H3 and H4 significantly decreased when 40% of the total N was applied as a single application at PI. Grain-filling is a process involving starch accumulation. The sucrose used for starch synthesis in the grain originates from the degradation of nonstructural carbohydrates (NSCs) assimilated in the leaf sheaths and stems before heading and from the translocation of carbon assimilates from the leaves after heading [34]. Zhang et al. [5] reported that NSCs translocated more slowly in response to high levels of panicle N compared with moderate levels. Only 37.9% of ^{13}C translocated after 20 days after heading under high-panicle N treatment in IIyou 107, while 63.8% translocated under moderate levels. Weather conditions also affect NSC translocation; the grain weight and seed-setting rate of *japonica* rice are maximal when the average daily temperature during grain-filling is 23.5–24 °C [35]. However, these parameters are severely affected when the daily average temperature is lower than 20 °C or when the lowest temperature is lower than 15 °C [36]. When the growth periods of the four hybrid rice varieties were compared, H1 and H2 were heading at the end of August and were mature on 9 and 16 October in 2017, respectively, while H3 and H4 were heading during 7–11 September and were mature at the end of October. Moreover, the low temperature during mid-October in 2017 had a short-term effect on H1 and H2 but had a long-term and severe effect on the grain-filling of H3 and H4. Therefore, in high-fertility soil, the effect of postponing topdressing-N on the yield of hybrid rice was related to the growth periods of the varieties and the weather conditions. Postponing topdressing-N application slowed the translocation of NSCs, which increased the probability of low-temperature stress on varieties that had longer growth periods.

(3) With respect to the hybrid *japonica* rice grown in low-fertility soil, a significant decrease in the number of effective panicles was observed when the ratio of tillering N decreased from 30% to 20%, indicating that postponing topdressing-N resulted in a N shortage during the early growth stage.

All of the above results showed that postponing topdressing-N had no obvious effect on increasing the grain yield of *japonica* rice in either high- or low-fertility soils. The results of these experiments therefore challenge the findings of Xu, who reported that increasing the ratio of panicle N had no effect on the yield of hybrid rice grown in high-fertility soil but could increase the grain yield of hybrid rice grown in low-fertility soil [18]. This discrepancy might be due to the different N application methods and soil type/texture in the two experiments. In contrast to other methods, increasing the ratio of panicle N by reducing both basal and tiller N decreased the proportion of only tiller N, while the ratio of basal N remained unchanged. Our previous research indicated that basal fertilizer was an effective long-term fertilizer and that the proportion of total N at the full heading stage was much greater from the basal N than from the tiller N and panicle N [7], especially in clayey paddy soils. Organic matter can act as a reservoir of plant nutrients [37] and supplies nutrients via mineralization, desorption, and binding to reduce nutrient leaching. Soil organic matter (SOM) decomposition and accumulation are influenced by soil texture [38], clay mineralogy [39], temperature, water content, and microbial activity [40,41]. Clay minerals can bind organic matter [42] and protect SOM from decomposition via physical protection by the formation of macroaggregates [43] and organo-mineral complexes [44]. Compared with sandy soils, the blue clayey soil in this experiment presented slower SOM decomposition, especially when the soil temperature was low in the early stage of growth; postponing topdressing-N by reducing the ratio of tillering N therefore adversely affected tiller development and decreased the number of effective panicles in the low-fertility soil. However, clayey soils have a strong fertility conservation capability, and our previous research showed that basal fertilizer-N, tillering fertilizer-N, and panicle fertilizer-N comprised 1.3%, 0.6%, and 0.4% of the soil N at the heading stage when 210 $kgNha^{-1}$ was applied at a ratio of 40%:30%:30% [7]. With an increase in soil temperature at the reproduction stage, the release of soil nutrients accelerated. Compared with the hybrid rice grown in the high-fertility soil, the rice grown in the low-fertility soil had 17.4% fewer effective panicles but 20.4% more grains per panicle, and no significant difference in grain yield was detected between the high- and low-fertility soils in 2016. Thus, the experiments carried out in the blue clayey paddy soil revealed that soil fertility affected mainly the occurrence of tillers at the early growth stage. Moreover, the adverse effects on grain yield were reduced by increasing the number of spikelets per panicle when there was no inclement weather during grain-filling, indicating that the N supply at the booting stage met the needs of rice growth and was not the yield-limiting factor in this study, even in the low-fertility soil. Therefore, in this blue clayey soil, the proportion of panicle N applied to *japonica* rice should not exceed 30%; otherwise, excessive fertilizer at PI will aggravate the instability of rice yields. However, due to the lack of relevant soil information support, the relationships between soil type, texture, and the effect of postponing N applications remain unexplored.

5. Conclusions

In the blue clayey paddy soil, postponing topdressing-N by decreasing the ratio of tillering N while accordingly increasing the panicle N from 20% to 40% did not increase grain yields. Although increasing the ratio of panicle N had no effect on the yield components of inbred varieties grown in both high- and low-fertility soils, the effects of postponing topdressing-N on hybrid *japonica* rice are related to variety, meteorological conditions, and soil fertility. Regarding hybrid rice grown in low-fertility soil, postponing topdressing-N had an adverse effect on grain yield by reducing the number of effective panicles, while postponing topdressing-N increased the probability of low-temperature stress on rice with long growth periods in hybrid varieties grown in high-fertility soil by reducing their seed-setting rate. The proportion of panicle N applied to *japonica* rice should not exceed 30% in clayey soils.

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