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Combined effect of nitrogen and phosphorous fertiliser on nitrogen absorption and utilisation in rice

Yating Zheng, Hong Chen, Guotao Yang, Rudan Wang, Nabi Farhan, Chong Li, Cheng Liang, Kaiqin Shen, Xuechun Wang, Yungao Hu**

Rice Research Institute, Southwest University of Science and Technology, Mianyang, Sichuan, P.R. China
Yating Zheng and Hong Chen contributed equally to this work.
**Corresponding authors: xuechunwang@swust.edu.cn, huyungao@swust.edu.cn*

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Abstract: The objectives of this study were to investigate the nitrogen (N) and phosphorus (P) balance fertilisation strategy in paddy fields and to evaluate the effects on N uptake and utilisation in rice. In 2017–2018, the experiment was conducted using cv. Deyou4727 rice with four different P fertiliser levels (0, 6.6, 13.2, and 26.4 kg/ha), marked as P0, P1, P2, P3 in turn, and four different N levels (0, 90, 150, and 270 kg/ha), similarly marked as N0, N1, N2, N3 in turn. The results showed that in the N-insufficient (N0, N1) environments, the P1 treatment increased N uptake and promoted transfer to the grain. However, high-P (P3) application increased the dry matter accumulation more than other P levels but limited the production and translocation of dry matter to some extent. In N-sufficient (N2, N3) environments, the P2 level increased crop yield and N use efficiency by 11.35% and 37.01%. Unlike P2, none-P (P0) and high-P levels decreased rice dry matter translocation and transport capacity, which further affected N uptake and utilisation in N-sufficient environments. Overall, the combination of the N application rate of 90 kg/ha and P application rate of 13.2 kg/ha, N application rate of 150, 270 kg/ha, and P application rate of 26.4 kg/ha had a high yield; strong nutrient accumulation and transfer ability. It was more inclined to balance N and P, which was beneficial to plant N absorption and utilisation.

Keywords: nitrogen and phosphorus ratio; nitrogen translocation; nitrogen uptake; nitrogen use efficiency

Agronomists have already achieved the goal of high and stable yield by using high-yield-producing rice breeds and the application of chemical fertilisers (Zhang et al. 2013). However, the inappropriate amount and method of fertilisation application made an urgent environmental concern, which needs to be addressed by agronomists (Ke et al. 2017). In the field, farmers insist on a tendency to apply more nutrients than the required amount for maximum crop growth to obtain high yields, especially N fertiliser (Pan et al. 2017). Excessive use of mineral fertilisers greatly increased production costs and caused serious environmental problems such as paddy soil deterioration and exacerbating global warming (Wang et al. 2021). Adjusting the fertilisation scheme to increase fertiliser utilisation efficiency is an important issue in agricultural rice production and a prerequisite for reassuring sustained high yield (Zheng et al. 2017).

N and P are important nutrients for rice growth, of which N is an important limiting factor in promoting grain growth and improving productivity (An et al. 2018). Both N and P rates are important factors that affect rice yield formation and production composition (Ma et al. 2022). N plays a vital role in

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all stages of rice growth. N fertiliser facilitated the promotion of tillering and the leaf area of the early stage of rice growth. Furthermore, the N application amount also affected panicle formation and photosynthetic product production in the later stage (Hou et al. 2019). Appropriate P application along with N fertiliser can have a positive impact on rice growth, such as increasing crop yield and improving the soil environment. The previous studies showed that excessive N fertiliser application intensified nutrient competition within the plant and reduced nutrient transport to the grains in the late growth stage, which ultimately led to low crop yield (Zhang et al. 2018). Besides, the excessive usage of P fertiliser caused a decrease in the leaf area index, which affects the photosynthesis process of cereal crops (Vinod and Heuer 2012).

Managing and controlling the N and P application ratio can effectively increase the yield components. Imbalanced and inadequate use of nutrients leads to a negative balance in soil (Shahane et al. 2018). It is generally believed that increasing P application has a positive effect on crop yield (Long and Yao 2020). Due to most of the P inputs being fixed or adsorbed by soil components, the bioavailability of P is low in conventional cropping systems (Rakotoson et al. 2014). Even under low P conditions, plants increase P uptake by modifying their root morphology, for example, increased root density (Vinod and Heuer 2012). Studies have shown that the combined application of N and P can significantly improve crop growth (Ye et al. 2019). The highly productive and nutrient uptake rates were mainly attributed to a more suitable match between a nutrient distribution and plant nutrient uptake (Hu and Chu 2020). Optimally managing nutrient supply and crop uptake has been critical to improving nutrient use efficiency and maintaining high yield (Che et al. 2016). Yield and fertiliser use efficiency in rice production have a direct relationship which maximizes fertiliser utilisation efficiency while ensuring high yield and less pollution (Cassman et al. 2003).

To explore the optimal best fertiliser combination to gain high yield in a minimum amount of mineral fertiliser, the study used four N and four P fertiliser application levels to grow cv. Deyou 4727 rice to study the combined and separate effects of N and P, with different fertiliser rates. The study's objectives are: (1) to evaluate the differences and response of rice dry matter accumulation, N absorbing under different N and P fertiliser application rates, and (2) to assess how N and P combined increases crop yield and fertiliser use efficiency.

MATERIAL AND METHODS

Experimental area. The experiments were carried out in the experimental base of Rice Research Institute of Southwest University of Science and Technology in Mianyang (31°03'N, 104°43'E, 500 m a.s.l.), Sichuan province, China, in 2017–2018. The area has a subtropical monsoon humid climate, with an annual average precipitation of 963.2 mm, an annual average temperature is 16.3 °C, an annual sunshine duration of about 1298.1 h, and an annual frost-free period of about 272 days. This trial was conducted from 2017–2018. The annual average temperatures in 2017 and 2018 were 14.4 and 14.3, with an annual average precipitation of 983.6 mm and 970.5 mm, respectively. The soil in the experimental field was sandy loam with 642 mg/kg total N, 503 mg/kg total P, 23 mg/kg available P, 46 mg/kg available K and 5.24 g/kg organic carbon, and pH is 7.47.

Experimental design. The experiment adopted a split-plot design – the experimental design comprised four N levels and four P levels. Fertiliser application rates for different N and P levels are shown in Table 1. There are 16 treatments consisting of various N or P levels. The dimension of the unit plot was 3.0 ×

Table 1. The application rates of the nitrogen (N) and phosphorus (P) application in this experiment

Treatment		N application (kg N/ha)	P application (kg P/ha)
N0	P0	0	0
	P1	0	6.6
	P2	0	13.2
	P3	0	26.4
N1	P0	90	0
	P1	90	6.6
	P2	90	13.2
	P3	90	26.4
N2	P0	150	0
	P1	150	6.6
	P2	150	13.2
	P3	150	26.4
N3	P0	270	0
	P1	270	6.6
	P2	270	13.2
	P3	270	26.4

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4.0 m (12 m^2). Each plot was separated by a ridge to avoid plots cross-contamination by water flow. Field trials were conducted in 2017 and 2018. The selected cultivar was Deyou4727, an indica three-line hybrid rice cultivar with a full growth period of about 158 days and is widely grown in the local area. Rice was cultivated from March to September 2017, 2018.

Field management. For the application of N and P, urea and superphosphate were used, respectively. N fertiliser was applied in two ways: base fertiliser (applied before crop transplanting) and panicle fertiliser (applied during young spike differentiation), with a ratio of 7 : 3. Similarly, P was applied as a basal application before the transplanting of rice. Herbicides were sprayed before rice seedling transplantation and after one week of transplantation. Weeds in the experimental field were removed manually. In addition, we use 375 g/ha of insecticide to control pests during the rice growth period. Chlorpyrifos ($C_9H_{11}Cl_3NO_3PS$) and triazophos ($C_{12}H_{16}N_3O_3PS$) were the main insecticides used. The rice was harvested at the mature stage and adjusted to the standard moisture content of 13.5% to determine the grain yield.

Dry matter accumulation and nutrition uptake. Within each experimental plot, 10 holes of rice were selected with replicated three times. The total number of tillers was counted to calculate the average number of rice stem tillers. Five fresh plant samples for each treatment were collected according to the average number of stem tillers at the full heading and maturity stages. For dry weight analysis, samples were dried at 105 °C for about 30 min for electro-thermal de-enzyme and then dried at 65 °C until constant weight. The dry straw was divided into three parts: leaves, stem, and panicle, for determination of the dry matter accumulation and distribution in the leaf, stem, and rice panicle.

We used a Kjeldahl analyser (Oesper 1934) to determine the N content of each part of the plant. Indicators of dry matter transport include an export percentage of the stem and sheath matter (EPMSS) and transition percentage of the stem and sheath matter (TPMSS) were evaluated by the formulae following (Ntanos and Koutroubas 2002):

$$\mathrm{EPMSS} = \frac{\mathrm{DMAS_F} - \mathrm{DMAS_M}}{\mathrm{DMAS_F}} \quad (1)$$

$$\mathrm{TPMSS} = \frac{\mathrm{DMAS_F} - \mathrm{DMAS_M}}{\mathrm{DMAE_M}} \quad (2)$$

Where: $DMAS_F$ – dry matter accumulation in stem and sheath at full heading stage; $DMAS_M$ – dry matter accumulation in stem and sheath at maturity stage; $DMAE_M$ – dry matter in panicles at maturity stage.

According to the method of Ye et al. (2013), the absorption of N was calculated. N uptake can be expressed as:

$$\mathrm{N_{up}} = \mathrm{TDMA} \times \mathrm{N_{tot}} \quad (3)$$

Where: N_{up} – amount of rice N uptake (kg/ha); TDMA – aboveground total dry matter accumulation (t/ha); N_{tot} – total N content of rice (g/kg).

N translocation, including the N translocation efficiency (NTE) and the N contribution efficiency (NCE), can be expressed as:

$$\mathrm{NTE} = \frac{\mathrm{N_F} - \mathrm{N_M}}{\mathrm{N_M}} \quad (4)$$

$$\mathrm{NCE} = \frac{\mathrm{N_F} - \mathrm{N_M}}{\mathrm{N_{MS}}} \quad (5)$$

Where: N_F and N_M – amounts of rice N uptake in stem or leaf at the full heading and mature stage (kg/ha); N_{MS} – N uptake in the panicle at the mature stage (kg/ha).

Nitrogen use efficiency. The agronomic efficiency (NAE); recovery efficiency (NRE); partial factor productivity (NPFP); contribution rate (NCR); and harvest index (NHI) of N fertiliser were computed using the following equation as suggested by Fageria (2001).

$$\mathrm{NAE} = \frac{\mathrm{Y} - \mathrm{Y_0}}{\mathrm{F}} \quad (6)$$

$$\mathrm{NRE} = \frac{\mathrm{N_{up}} - \mathrm{N_{0up}}}{\mathrm{F}} \quad (7)$$

$$\mathrm{NPFP} = \frac{\mathrm{Y}}{\mathrm{F}} \quad (8)$$

$$\mathrm{NCR} = \frac{\mathrm{Y} - \mathrm{Y_0}}{\mathrm{Y}} \quad (9)$$

$$\mathrm{NHI} = \frac{\mathrm{N_p}}{\mathrm{N_{up}}} \quad (10)$$

Where: Y_0 and N_{0up} – crop yield and the total N uptake of aboveground plant parts in the N0 treatment; Y – grain yield in the other fertiliser treatments; F – applied N fertiliser rate; N_p – N uptake in the panicles at maturity stage.

Statistical analysis. To test for differences among the different treatments, an analysis of variance was performed using SPSS version 20.0. (SPSS Statistics, SPSS Inc., Chicago, USA). Mean comparison among treatments was based on the least significant difference (*LSD*) test at the 5% probability level. Graphs and tables were drawn using Excel (Microsoft Window, USA) and Origin 2018 (Originlab, USA).

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Table 2. Effects of different nitrogen (N) and phosphorus (P) application rates on grain yield and its components of rice in 2017

Treatment		Spikelets per panicle	Productive panicle (10^6/ha)	Grain filling (%)	1 000-grain-weight (g)	Yield (t/ha)
N0	P0	235.71 ± 18.39^{bcde}	1.26 ± 0.10^{g}	94.81 ± 1.20^{a}	28.07 ± 0.21^{bc}	8.08 ± 0.06^{f}
	P1	205.33 ± 13.05^{de}	1.32 ± 0.10^{fg}	91.60 ± 3.73^{b}	28.03 ± 0.64^{bc}	7.22 ± 0.36^{g}
	P2	221.00 ± 9.79^{cde}	1.26 ± 0.10^{g}	91.17 ± 4.41^{b}	28.62 ± 0.86^{bc}	7.27 ± 0.48^{fg}
	P3	237.65 ± 17.52^{bcd}	1.32 ± 0.10^{fg}	93.49 ± 0.71^{ab}	27.51 ± 0.19^{c}	7.79 ± 0.49^{fg}
N1	P0	240.19 ± 26.90^{abc}	1.50 ± 0.10^{de}	95.84 ± 0.67^{a}	28.26 ± 0.82^{bc}	9.51 ± 0.41^{e}
	P1	254.17 ± 20.26^{abc}	1.44 ± 0.10^{ef}	95.78 ± 1.16^{a}	27.55 ± 0.25^{bc}	9.13 ± 0.64^{e}
	P2	203.68 ± 12.13^{e}	1.68 ± 0.10^{bc}	95.85 ± 2.07^{a}	28.10 ± 0.31^{bc}	9.14 ± 0.65^{e}
	P3	241.00 ± 14.65^{abc}	1.44 ± 0.10^{ef}	95.05 ± 1.69^{a}	27.74 ± 0.80^{bc}	8.96 ± 0.46^{e}
N2	P0	243.10 ± 7.16^{abc}	1.80 ± 0.10^{b}	95.44 ± 1.94^{a}	27.80 ± 0.46^{bc}	11.60 ± 0.22^{cd}
	P1	204.53 ± 25.16^{e}	1.80 ± 0.10^{b}	96.77 ± 0.43^{a}	29.35 ± 0.20^{bc}	10.82 ± 0.23^{d}
	P2	225.04 ± 15.30^{cde}	1.98 ± 0.18^{a}	96.46 ± 0.34^{a}	28.79 ± 0.74^{bc}	12.34 ± 0.86^{abc}
	P3	267.70 ± 3.01^{ab}	1.56 ± 0.10^{cde}	95.70 ± 1.85^{a}	28.05 ± 0.76^{bc}	10.94 ± 0.31^{d}
N3	P0	225.80 ± 18.79^{cde}	1.80 ± 0.10^{b}	96.98 ± 0.38^{a}	28.71 ± 0.30^{bc}	11.88 ± 0.32^{bc}
	P1	236.31 ± 15.60^{bcde}	1.80 ± 0.10^{b}	96.55 ± 0.60^{a}	29.47 ± 0.39^{bc}	12.63 ± 0.69^{ab}
	P2	249.22 ± 17.09^{abc}	1.98 ± 0.10^{a}	95.79 ± 0.63^{a}	28.37 ± 0.23^{bc}	12.92 ± 0.78^{a}
	P3	271.64 ± 22.36^{a}	1.62 ± 0.10^{cd}	96.04 ± 0.21^{a}	29.77 ± 0.13^{a}	12.92 ± 0.08^{a}
F-value						
N		2.94*	131.50**	9.95**	2.91*	278.06**
P		10.68**	15.50**	0.12	0.55	1.87
N × P		2.56*	6.94**	1.08	0.91	3.79**

Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments (P < 0.05, Duncan's test). *P < 0.05; **P < 0.01

RESULTS

Grain yield and its components. Tables 2 and 3 showed the effects of N and P application and their interaction on rice yield and its constituent factors. While in none N (N0) or low N (N1), P application had no significant improvement in terms of crop yield, and even in a high P (P3) environment, it had a significantly low yield. The N2 treatment with P2 increased the yield of crops by increasing the number of spikelets per panicle and productive panicle. Compared with P1, the number of spikelets per panicle in P2 increased by 9.11%, but there was no significant difference. At the P2 level, the productive panicle was 9.09%, 21.21% higher than the P1 and P3 treatments in the N2 environment. At the N3 level, the input of P2 and P3 increased crop yield significantly, compared with P0, but there was no significant difference among the P1, P2, and P3 treatments.

The results showed that under the experimental conditions, when N fertiliser was insufficient (N0 and N1), only supplementing P fertiliser could not effectively improve crop yield. Unlike P, N application had a significant impact, and when combined with P fertiliser, it significantly improved the productive panicle and other yield components. Whatever P was sufficient or not, rice yield continued to increase with increased N fertiliser application.

Dry matter accumulation. Under different N fertiliser levels, the amount of P applied mainly affected the total dry matter accumulation (TDMA) of the crop in the full heading and maturity stage (Figure 1). The effect of changing the P application rate on TDMA showed different trends in each N treatment. Under none N treatment, the lowest TDMA of these two years was found in the P2 treatment. Under the N1, the TDMA in the P3 treatment was increased by 7.16–11.22%, compared with P0, P1, and P2. Under N2 application, the TDMA of rice increased dramatically and then decreased with the increase of P rates. In the high-N treatment, increasing P rates had no significant effect on dry matter accumulation, which

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Table 3. Effects of different nitrogen (N) and phosphorus (P) application rates on grain yield and its components of rice in 2018

Treatment		Spikelets per panicle	Productive panicle (10^6/ha)	Grain filling (%)	1 000-grain-weight (g)	Yield (t/ha)
N0	P0	171.10 ± 17.7^{abc}	1.26 ± 0.10^{f}	93.39 ± 1.99^{ab}	27.97 ± 1.85^{de}	5.91 ± 0.53^{f}
	P1	168.90 ± 5.37^{abc}	1.26 ± 0.00^{f}	93.00 ± 3.28^{ab}	26.59 ± 1.98^{e}	5.99 ± 0.52^{f}
	P2	165.28 ± 27.36^{abc}	1.38 ± 0.10^{def}	94.81 ± 1.12^{ab}	27.85 ± 0.36^{de}	6.30 ± 0.33^{ef}
	P3	174.54 ± 8.96^{abc}	1.32 ± 0.10^{ef}	94.42 ± 0.74^{ab}	29.10 ± 1.29^{bcd}	6.35 ± 0.40^{ef}
N1	P0	165.78 ± 9.33^{abc}	1.38 ± 0.10^{def}	91.92 ± 2.55^{b}	27.67 ± 0.75^{de}	6.47 ± 0.50^{ef}
	P1	172.61 ± 15.21^{abc}	1.56 ± 0.21^{cde}	93.72 ± 1.97^{ab}	28.82 ± 1.43^{cde}	7.46 ± 0.55^{bd}
	P2	169.46 ± 17.31^{abc}	1.44 ± 0.10^{def}	94.87 ± 0.87^{ab}	31.37 ± 1.96^{ab}	7.10 ± 0.56^{de}
	P3	175.79 ± 16.19^{ab}	1.44 ± 0.10^{def}	95.13 ± 0.66^{a}	30.70 ± 1.62^{abc}	6.96 ± 0.18^{de}
N2	P0	183.00 ± 13.82^{a}	1.44 ± 0.00^{def}	95.07 ± 1.22^{a}	30.00 ± 0.92^{bcd}	8.19 ± 0.40^{bc}
	P1	155.13 ± 13.02^{cd}	1.56 ± 0.10^{cde}	93.44 ± 1.66^{ab}	29.15 ± 0.50^{bcd}	8.30 ± 0.24^{bc}
	P2	160.19 ± 12.25^{abc}	1.80 ± 0.31^{bc}	94.61 ± 1.60^{ab}	29.58 ± 0.82^{bcd}	8.85 ± 0.67^{ab}
	P3	154.22 ± 9.52^{cd}	1.62 ± 0.18^{bcd}	95.69 ± 0.75^{a}	29.41 ± 0.57^{bcd}	8.46 ± 0.58^{bc}
N3	P0	169.18 ± 9.79^{abc}	1.62 ± 0.31^{bcd}	94.57 ± 1.19^{ab}	29.84 ± 1.13^{bcd}	8.19 ± 0.27^{bc}
	P1	151.54 ± 10.79^{cd}	1.74 ± 0.10^{bc}	91.45 ± 1.12^{b}	29.15 ± 1.06^{bcd}	9.54 ± 0.36^{a}
	P2	147.99 ± 6.43^{d}	2.10 ± 0.10^{a}	95.12 ± 1.29^{a}	32.54 ± 2.03^{a}	9.53 ± 0.61^{a}
	P3	155.88 ± 1.16^{cd}	1.86 ± 0.10^{ab}	95.57 ± 0.20^{a}	30.85 ± 0.65^{abc}	9.42 ± 0.78^{a}
F-value						
N		3.11*	27.87**	1.35^{ns}	9.01**	92.43**
P		1.76	5.12**	12.02**	6.85**	2.51
N × P		1.08	1.70	2.00	1.13	2.15

Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments (P < 0.05, Duncan's test). *P < 0.05; **P < 0.01

may be related to the maximum potential of plant dry matter accumulation.

The above findings showed that when N was insufficient, the P3 treatment increased crop dry matter accumulation capacity and sometimes reached significant difference levels compared to other P levels. While N was sufficient (N2, N3), the dry matter accumulation ability of rice was better than that of P1 in P0, P2, and P3.

Dry matter transport. In the N0 treatment, increasing the application of P fertiliser resulted in an intense decrease in the dry matter transport capacity of the stem sheath, which was more significant in the year 2018 than in 2017 (Figure 2). At the N1 level, the dry matter transport capacity of the stem sheath showed a trend of first decreasing and then increasing with the increase of the P rate. In the N2 treatment, the P1 application maintained high dry matter transport efficiency with 39.38–53.23%, and when the P rate increased to P3, the dry matter transport was greatly restricted. The N3P2 treatment showed a slightly higher outflow and transport rate of stem-sheath material than N3P0, N3P1, and N3P3.

It showed that when the N rate was insufficient, the application of P fertiliser restricted the export and transfer of stem-sheath dry matter to a certain extent. When N was sufficient, both none and high P application caused dry matter outflow and transport decline.

Nitrogen uptake and translocation. From the two-year results (Figure 3), when the rate of P application was P1, the N uptake of the full heading stage was higher in N0 than in other P treatments. This part of the difference was mainly due to the significantly increased N uptake of 63.25–82.90% in the stem and sheath of the P1 treatment, compared to other treatments. Similarly, the P1 treatment maintained a higher N translocation efficiency and contribution rate to grain (Tables 4 and 5). At the N0, P3 treatment increased the N uptake of the plants by 24.38–55.10% in the maturity stage.

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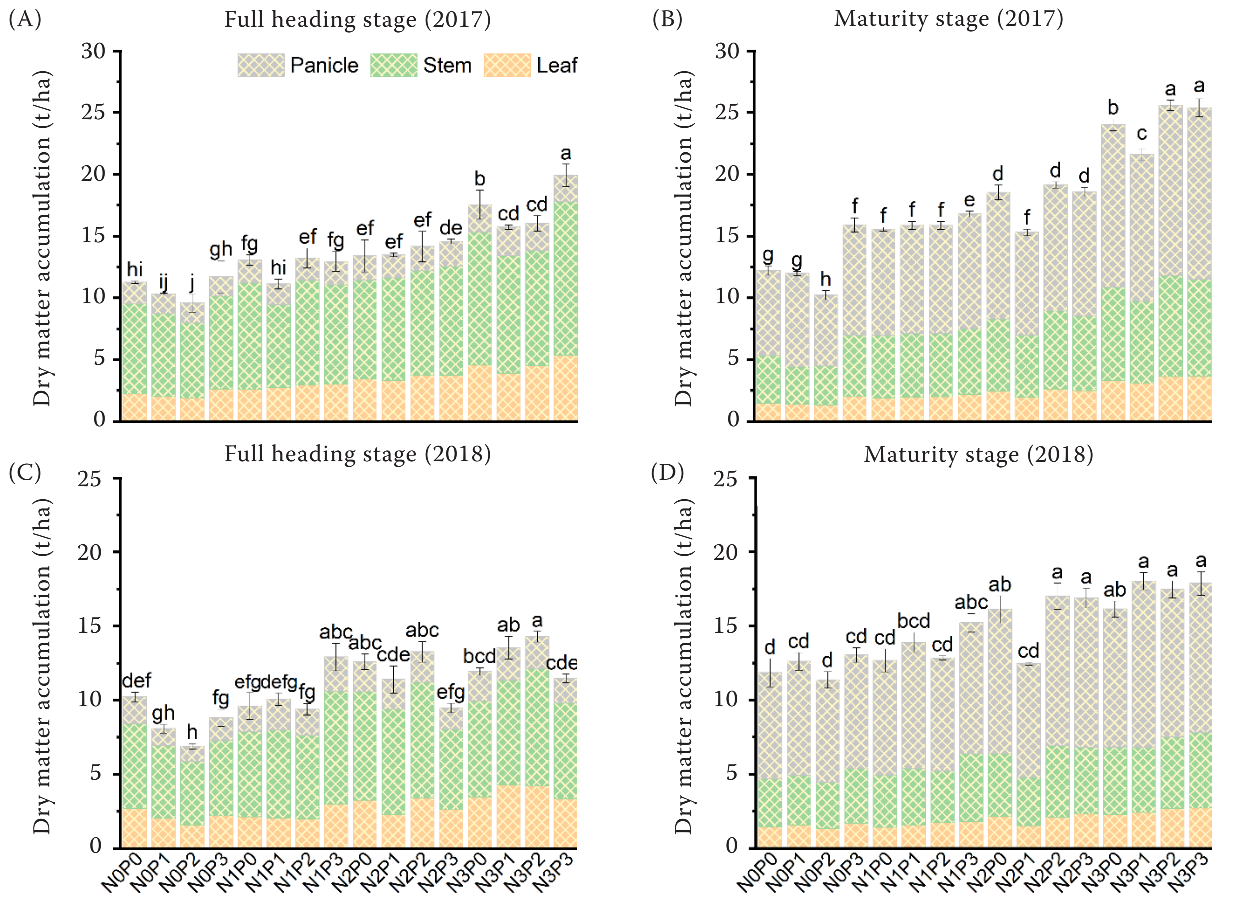

Figure 1. Effect of different fertiliser management practices on total dry matter accumulation and distribution in different parts of rice at full heading (A) 2017 and (C) 2018, and maturity (B) 2017 and (D) 2018 stage. The vertical error bar represents the standard deviation of the mean (n = 3). Different letters indicate a significant difference at P < 0.05 (Duncan's test)

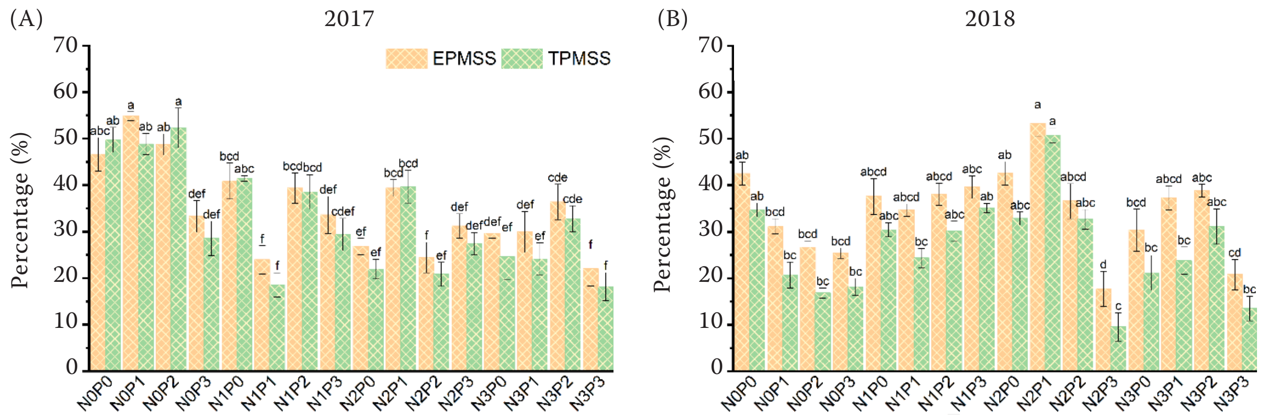

Figure 2. Effect of different fertiliser management practices on dry matter transport of rice in (A) 2017 and (B) 2018. EPMSS – export percentage of the stem and sheath matter; TPMSS – transition percentage of the stem and sheath matter. The values represent the mean of three replicates. Different letters indicate a significant difference at P < 0.05 (Duncan's test)

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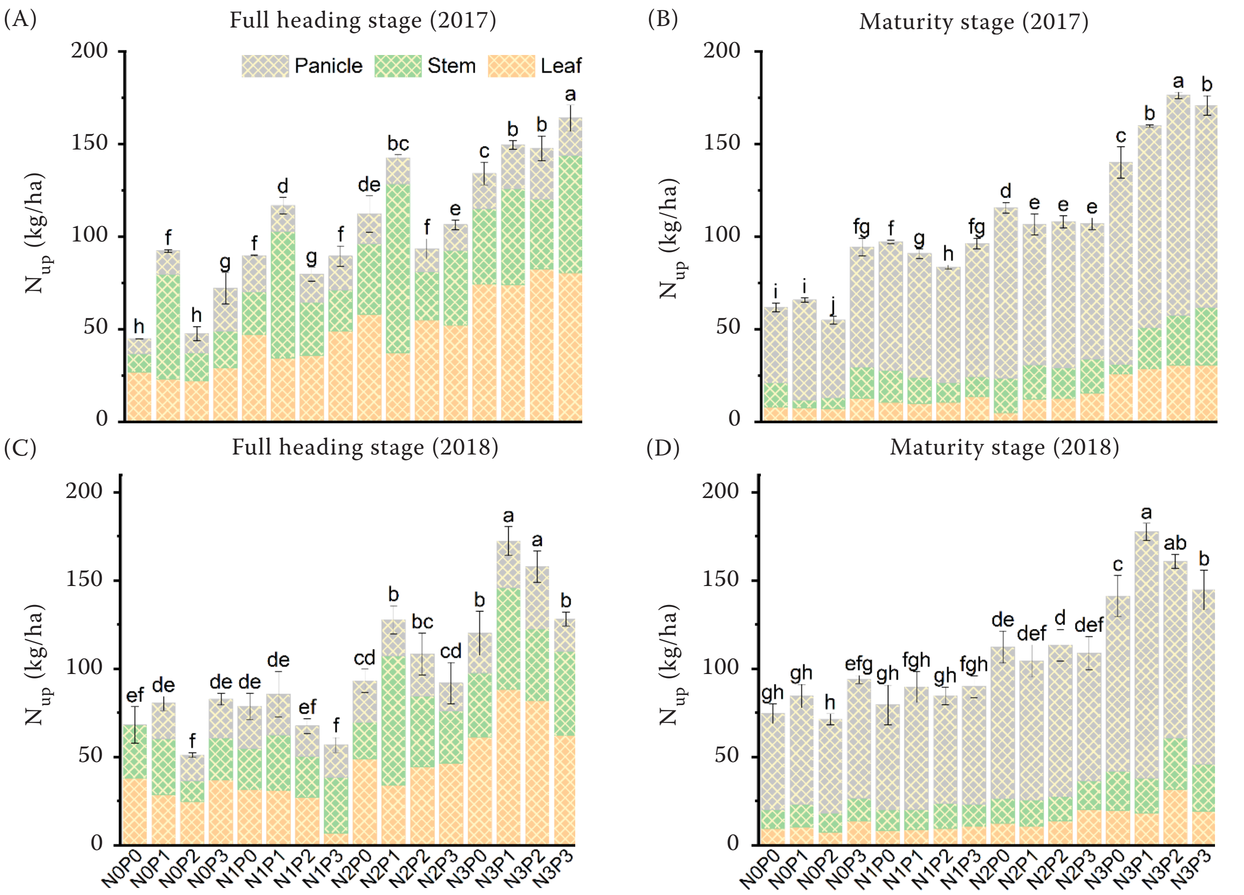

Figure 3. Effect of different fertiliser management practices on nitrogen uptake (N_{up}) and distribution in different parts of rice at full heading (A) 2017 and (C) 2018, and maturity (B) 2017 and (D) 2018 stage. The vertical error bar represents the standard error of the mean (n = 3). Different letters indicate a significant difference at P < 0.05 (Duncan's test)

In both N1 and N2 treatments, the P2 and P3 resulted in low N uptake. In contrast with P2 and P3, P0 and P1 resulted in an average increase of 18.06 kg/ha and 21.55 kg/ha in N uptake, respectively. At the N1 level, stem N's translocation and contribution rate significantly increased by 41.07% and 76.88% in the P1 treatment compared with other treatments.

Under the N3 level, the high N uptake of rice was observed at P1 and P2 treatments. Based on the results of the two years, the N uptake in P3 treatment decreased by 14.52–22.34% compared with P1 and P2. In the P2 treatment, a lower rate of stem N transport and contribution was observed.

This result showed that when the N application rate was insufficient, P1 increased the N absorption of the stem sheath at the full heading stage and promoted N transport into the grain, while the total N uptake of rice treated with P3 was higher at the mature stage. Excessive P application reduced the uptake and translocation of N under sufficient N fertiliser.

Nitrogen use efficiency. Different N and P application doses influenced N to use efficiency for two years (Tables 6 and 7). When no N fertiliser was applied, NHI significantly increased by 32.49% in the P3 treatment compared to other P levels (2017). While in the N1 application with P1 and P2, the NAE and NCR increased by significantly 31.32% and 32.28% compared with those in P0 and P3 on average. But from NRE, P2 was significantly improved by 12.66–68.64%, compared with P1. There were no significant differences in NPFP between all the P levels. Under the N2 condition, higher NAE and NRE were obtained in the P2 treatment. Compared with P1 and P3, the maximum increase of NAE and NRE separately reached 28.96% and 76.21% in the P2 treatment. At N3, increasing P fertiliser had a no-significant effect on NAE and NPFP. Taken together with 2-year data, higher NRE and NCR were obtained during P2. Increasing the application of P fertiliser resulted in a significant decrease in NHI

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Table 4. Effects of different nitrogen (N) and phosphorus (P) application rates on N translocation ability in 2017

Treatment		NTE (%)		NCE (%)	
		stem	leaf	stem	leaf
N0	P0	25.88 ± 0.94^{f}	70.36 ± 1.13^{cd}	10.63 ± 0.26^{h}	59.04 ± 0.23^{bcd}
	P1	92.57 ± 0.16^{a}	66.64 ± 0.83^{cdef}	126.75 ± 1.13^{a}	37.51 ± 1.41^{g}
	P2	59.97 ± 1.76^{cd}	67.97 ± 1.10^{cd}	28.79 ± 1.94^{ef}	47.90 ± 1.44^{defg}
	P3	16.19 ± 1.22^{g}	55.01 ± 1.13^{h}	8.50 ± 0.79^{h}	39.66 ± 1.74^{g}
N1	P0	25.76 ± 0.37^{f}	77.17 ± 0.97^{b}	11.94 ± 3.43^{h}	73.23 ± 4.61^{a}
	P1	79.82 ± 0.80^{b}	70.52 ± 1.07^{cd}	103.05 ± 3.43^{c}	45.70 ± 3.08^{efg}
	P2	63.25 ± 1.98^{c}	70.24 ± 0.12^{cd}	38.34 ± 1.94^{d}	53.50 ± 3.70^{cde}
	P3	52.11 ± 1.05^{de}	71.95 ± 1.93^{c}	21.81 ± 1.22^{fg}	65.83 ± 1.04^{abc}
N2	P0	49.90 ± 1.03^{e}	91.26 ± 1.25^{a}	25.54 ± 0.79^{f}	70.40 ± 4.92^{ab}
	P1	79.64 ± 0.61^{b}	66.98 ± 1.41^{cde}	117.98 ± 3.11^{b}	40.99 ± 2.40^{fg}
	P2	34.67 ± 1.48^{f}	77.07 ± 0.12^{b}	13.91 ± 0.57^{gh}	63.93 ± 1.35^{abc}
	P3	54.44 ± 1.73^{cde}	69.84 ± 1.56^{cd}	37.29 ± 0.89^{de}	62.00 ± 1.14^{abc}
N3	P0	87.42 ± 0.19^{ab}	65.13 ± 1.08^{defg}	40.14 ± 0.46^{d}	54.22 ± 2.20^{cde}
	P1	57.25 ± 2.68^{cde}	61.23 ± 1.98^{g}	34.78 ± 0.86^{de}	53.13 ± 2.42^{cdef}
	P2	29.10 ± 1.06^{f}	62.53 ± 1.11^{efg}	12.06 ± 0.65^{h}	56.71 ± 1.84^{cde}
	P3	50.73 ± 1.00^{de}	61.63 ± 1.39^{fg}	36.33 ± 0.41^{de}	55.85 ± 1.48^{cde}
F-value					
N		104.50**	37.31**	629.97**	17.48**
P		4.80**	60.36**	27.97**	10.51**
N × P		57.05**	9.60**	81.52**	3.18**

NTE – nitrogen translocation efficiency; NCE – nitrogen contribution efficiency. Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments (P < 0.05, Duncan's test). *P < 0.05; **P < 0.01

at the N3 treatment, and the lowest values were found in P1 or P2 treatment. The results showed that combining all indicators on N use efficiency in all N treatments was higher when the P application rate was 13.2 kg/ha.

DISCUSSION

Yield and its components. Appropriate N and P are the keys to the high yield of cereal crops. Reportedly, a suitable dosage of N and P increases the panicle number and the number of grains while retaining a stable filled grain rate and 1 000-grain weight, which was assumed as the key to increasing rice yield. Previous studies believed that increasing the number of effective panicles per unit area is an important way to improve rice yield (Ren et al. 2019). N and P supplementation are the most important crop management practices that significantly affect rice growth and yield formation. In this study, the effective panicle number and 1 000-grain weight were positively correlated with yield (r = 0.706**; r = 0.572**). The number of effective panicles might increase by increasing the amount of N applied at each P treatment. The productive panicle also increased by increasing the P rate in N0 or N1, while that index decreased in N2 and N3 treatments. The P application rate required to reach the highest yield under each N rate showed different results. The interaction between the P rate and the N rate can coordinate the comprehensive advantages of yield components to achieve higher yields.

Nutrient translocation and utilisation. The formation of crop yield is the result of the process of dry matter production, accumulation and distribution in plants (Meena et al. 2019). High accumulation and uptake of nutrients were the material basis for improving above-ground biomass and crop yield. Fertiliser configuration significantly impacted crop nutrient production, accumulation, absorption and utilisation (Shahane et al. 2018). Appropriate fertilisation was conducive to producing dry matter and

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Table 5. Effects of different nitrogen (N) and phosphorus (P) application rates on N translocation ability in 2018

Treatment		NTE (%)		NCE (%)	
		stem	leaf	stem	leaf
N0	P0	64.48 ± 4.85^{b}	73.72 ± 1.60^{ab}	36.13 ± 1.35^{bcd}	51.96 ± 2.91^{ab}
	P1	60.29 ± 3.70^{bc}	63.02 ± 2.51^{bcde}	48.44 ± 2.91^{b}	43.95 ± 3.83^{b}
	P2	17.27 ± 0.10^{g}	69.77 ± 2.69^{abc}	5.42 ± 0.33^{e}	44.82 ± 3.55^{b}
	P3	43.86 ± 4.38^{de}	62.79 ± 3.31^{bcde}	23.61 ± 1.24^{bcde}	51.32 ± 2.82^{ab}
N1	P0	49.90 ± 1.12^{d}	73.18 ± 3.98^{ab}	37.15 ± 2.55^{bcd}	69.29 ± 4.18^{ab}
	P1	62.98 ± 6.43^{bc}	71.62 ± 2.63^{abc}	43.33 ± 3.06^{c}	47.90 ± 6.84^{b}
	P2	40.30 ± 5.21^{def}	64.46 ± 2.51^{bcde}	24.19 ± 1.94^{bcde}	45.21 ± 4.07^{b}
	P3	60.00 ± 2.24^{bc}	53.92 ± 1.08^{e}	40.20 ± 1.22^{bc}	47.70 ± 2.19^{b}
N2	P0	33.54 ± 2.16^{ef}	74.27 ± 1.44^{ab}	12.07 ± 4.84^{de}	59.78 ± 1.89^{ab}
	P1	79.34 ± 4.72^{a}	67.53 ± 1.67^{abcd}	101.91 ± 2.31^{a}	40.23 ± 2.92^{b}
	P2	65.50 ± 4.50^{b}	68.45 ± 2.01^{abcd}	49.73 ± 3.60^{b}	55.01 ± 6.93^{ab}
	P3	45.50 ± 1.83^{de}	56.38 ± 1.05^{de}	23.69 ± 2.83^{bcde}	46.23 ± 3.37^{b}
N3	P0	39.08 ± 2.95^{def}	67.22 ± 1.75^{abcd}	18.65 ± 2.59^{cde}	53.71 ± 5.99^{ab}
	P1	65.55 ± 1.43^{b}	78.59 ± 1.01^{a}	33.73 ± 1.85^{bcd}	62.75 ± 2.20^{ab}
	P2	28.16 ± 1.37^{fg}	60.39 ± 1.93^{cde}	18.24 ± 1.96^{cde}	78.21 ± 4.04^{a}
	P3	43.74 ± 2.62^{de}	68.97 ± 5.05^{abc}	26.36 ± 1.15^{bcde}	53.64 ± 2.50^{ab}
F-value					
N		29.03**	96.53**	13.73**	5.36**
P		5.99**	61.20**	5.74**	4.80**
N × P		10.01**	65.60**	5.38**	3.83**

NTE – nitrogen translocation efficiency; NCE – nitrogen contribution efficiency. Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments (P < 0.05, Duncan's test). *P < 0.05; **P < 0.01

could effectively promote the transport of nutrients to the grain. Compared with the application of a single fertiliser, the combined application of various nutrient fertilisers significantly improves rice's growth characteristics. In this study, when the N fertiliser application rate was 0 kg/ha, the increase in the P fertiliser application rate did not significantly improve the accumulation of dry matter in plants and even decreased the further transfer of nutrients to rice grains. Similarly, when the N application rate reached 90 kg/ha, increasing the input of P fertiliser could promote the effective accumulation of dry crop matter. By increasing the application of P fertiliser, the production of dry matter in crops was significantly affected, and we conjectured that this might depend on the improvement of crop photosynthetic capacity (Duncan et al. 2018a).

The absorption capacity of nutrients matters during the growth period of rice and seriously affects crop growth and development. After nutrient absorption, various physiological and metabolic processes such as assimilation, transportation, storage and redistribution occur. N responses mediated by P are one of the important parts of crop N and P interactions. N and P interaction had a significant regulatory effect on N uptake and utilisation in rice (Duncan et al. 2018b). In this study, under the N0 treatment, increasing the amount of P fertiliser promoted the uptake of N by plants. Consistent with previous research results, it is believed that proper application of P fertiliser has a positive effect on N absorption (Du et al. 2022). Furthermore, the amount of N uptake in the early growth stage of rice is very important for the establishment of the internal N pool of the plant. The full heading stage is one of the peak periods of N absorption in rice. At this stage, the N absorption capacity significantly affects the level of crop panicle formation, which is an important prerequisite for ensuring high yield. When the N application rate was N1, the N uptake at the full heading stage of P1 treatment was about 27.53% higher than that of P2 and P3. Compared with P0, due to the increase in P

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Table 6. Effects of different nitrogen (N) and phosphorus (P) application rates on N use efficiency in 2017

Treatment		NAE (kg/kg)	NRE (%)	NPFP (kg/kg)	NCR (%)	NHI (%)
N0	P0	–	–	–	–	65.77 ± 1.54[hi]
	P1	–	–	–	–	53.57 ± 0.34[j]
	P2	–	–	–	–	76.22 ± 0.58[c]
	P3	–	–	–	–	86.36 ± 2.01[a]
N1	P0	15.87 ± 3.95[de]	39.23 ± 1.90[b]	105.64 ± 4.60[a]	14.93 ± 2.12[fg]	71.34 ± 1.87[f]
	P1	21.18 ± 4.66[bcd]	27.74 ± 3.03[f]	101.42 ± 7.07[a]	20.77 ± 2.45[f]	54.36 ± 0.66[j]
	P2	20.78 ± 5.13[bcd]	31.76 ± 1.03[de]	101.60 ± 7.27[a]	20.34 ± 3.30[f]	72.56 ± 0.70[ef]
	P3	12.95 ± 2.40[e]	4.12 ± 0.60[h]	99.50 ± 5.13[a]	12.91 ± 1.90[g]	74.62 ± 1.18[de]
N2	P0	23.50 ± 1.80[bc]	35.86 ± 0.49[bc]	77.36 ± 1.45[bc]	30.35 ± 1.74[de]	79.34 ± 0.39[b]
	P1	23.97 ± 3.15[b]	27.16 ± 2.65[f]	72.11 ± 1.52[c]	33.21 ± 1.96[cde]	70.93 ± 0.62[fg]
	P2	33.74 ± 4.08[a]	35.40 ± 0.79[bcd]	82.24 ± 1.75[b]	40.96 ± 2.95[ab]	72.64 ± 1.12[ef]
	P3	21.00 ± 2.97[bcd]	8.42 ± 0.97[g]	72.93 ± 2.04[c]	28.80 ± 2.95[e]	68.09 ± 0.99[gh]
N3	P0	16.85 ± 0.22[cde]	28.98 ± 1.87[ef]	46.78 ± 1.78[d]	36.03 ± 0.46[bcd]	77.76 ± 1.52[bc]
	P1	21.11 ± 1.09[bcd]	34.80 ± 0.62[cd]	47.86 ± 2.87[d]	43.99 ± 20.24[a]	53.33 ± 0.77[j]
	P2	17.07 ± 1.26[bcde]	44.93 ± 0.90[a]	44.01 ± 1.17[d]	38.81 ± 3.04[abc]	67.30 ± 0.67[h]
	P3	18.99 ± 2.03[bcde]	28.30 ± 1.95[ef]	47.84 ± 0.30[d]	39.69 ± 3.08[abc]	63.84 ± 0.75[i]
F-value						
N		14.05**	93.32**	498.71**	131.55**	463.86**
P		4.48*	525.16**	3.27*	5.22**	326.65**
N × P		3.82**	71.73**	2.19	2.99*	146.48**

NAE – nitrogen agronomic efficiency; NRE – nitrogen recovery efficiency; NPFP – nitrogen partial factor productivity; NCR – nitrogen contribution rate; NHI – nitrogen harvest index. Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments ($P < 0.05$, Duncan's test). *$P < 0.05$; **$P < 0.01$

content, the nutrient balance was promoted, thereby increasing the utilisation rate of nutrient elements, which is beneficial to crop absorption (Vinod and Heuer 2012). However, the continuous increase of P fertiliser from P1 to P2 and P3 led to the imbalance of N and P, affecting plants' absorption and utilisation of N. Under the N2 and N3 levels, when the P application rate increased to P2, the N uptake showed a significant increasing trend. Furthermore, applying P fertiliser to pathogens' occurrence may contribute to understanding these results (Yang et al. 2022). Low P reduced the efficiency of N uptake and utilisation, attributed to limiting plant root growth and activity (Chin et al. 2009).

Increased N uptake was the reason why N and P interaction helps to improve yield and N use efficiency. N use efficiency was closely related to improved grain yield with combined N and P applications (Lu et al. 2019). Unreasonable fertilisation management reduced N use efficiency and increased production cost and environmental risk. Huang et al. (2022) studied N efficiency using the same cultivar, Deyou 4727, considering that high N use efficiency is the key to high yield. When the N application rate is above the N2 level, a sufficient supply of N enables the plants to have good growth characteristics. The highest dry matter accumulation was obtained while maintaining high transport efficiency when P fertiliser was supplemented to the P2 level. The continued increase in the amount of P fertiliser application affects the absorption and utilisation of N in a crop, thereby reducing the efficiency of N fertiliser use. Excessive P fertiliser application did not lead to better benefits, and Yang et al. (2021) also found that the application of P above a certain level had no significant benefit for rice cultivation. Meanwhile, it may be caused greater environmental stress, which is consistent with the findings of Gautam et al. (2021).

To coordinate the balance between rice yield and N utilisation, it is necessary to achieve efficient absorption and operation between rice source and sink organs without sacrificing yield. Crops respond

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Table 7. Effects of different nitrogen (N) and phosphorus (P) rates on N use efficiency in 2018

Treatment		NAE (kg/kg)	NRE (%)	NPFP (kg/kg)	NCR (%)	NHI (%)
N0	P0	–	–	–	–	73.00 ± 1.39^{abcdef}
	P1	–	–	–	–	69.12 ± 1.11^{efg}
	P2	–	–	–	–	73.79 ± 1.80^{abcdef}
	P3	–	–	–	–	71.58 ± 2.25^{bcdefg}
N1	P0	15.26 ± 1.12^{ab}	14.08 ± 1.64^{cde}	82.90 ± 6.14^{a}	20.58 ± 2.67^{bc}	74.75 ± 0.80^{abcde}
	P1	5.36 ± 1.30^{b}	7.40 ± 0.37^{ef}	71.87 ± 5.58^{b}	6.65 ± 0.63^{d}	77.21 ± 1.95^{ab}
	P2	8.79 ± 0.67^{ab}	23.60 ± 0.70^{abc}	78.84 ± 6.25^{a}	10.95 ± 0.15^{cd}	70.83 ± 2.74^{cdefg}
	P3	6.70 ± 0.18^{ab}	2.65 ± 0.23^{f}	77.28 ± 2.05^{ab}	8.55 ± 0.90^{d}	74.11 ± 1.24^{abcde}
N2	P0	15.23 ± 0.79^{ab}	25.15 ± 1.06^{ab}	54.61 ± 2.64^{c}	27.90 ± 1.05^{ab}	76.51 ± 1.59^{abc}
	P1	15.45 ± 1.04^{ab}	8.13 ± 0.96^{ef}	55.36 ± 1.60^{c}	27.74 ± 1.40^{ab}	77.90 ± 2.72^{a}
	P2	17.00 ± 1.65^{a}	27.42 ± 0.87^{ab}	59.03 ± 2.47^{c}	28.36 ± 0.74^{ab}	75.50 ± 2.35^{abcd}
	P3	14.03 ± 1.15^{ab}	9.88 ± 0.75^{def}	56.38 ± 2.88^{c}	24.46 ± 0.68^{abc}	66.48 ± 1.07^{gh}
N3	P0	8.45 ± 0.77^{ab}	24.67 ± 0.94^{abc}	30.33 ± 0.98^{d}	27.71 ± 0.50^{ab}	70.26 ± 2.67^{abcdef}
	P1	13.14 ± 0.21^{ab}	5.09 ± 0.24^{ef}	35.32 ± 1.33^{d}	37.03 ± 0.79^{a}	62.41 ± 1.83^{h}
	P2	11.93 ± 0.69^{ab}	32.81 ± 1.47^{a}	35.28 ± 1.27^{d}	33.74 ± 1.10^{ab}	62.26 ± 2.19^{h}
	P3	11.35 ± 0.41^{ab}	18.76 ± 0.95^{bcd}	34.88 ± 1.90^{d}	32.48 ± 1.34^{ab}	68.06 ± 2.33^{fg}
F-value						
N		14.05**	10.04**	498.71**	131.55**	20.51**
P		4.48*	8.91**	3.27*	5.22**	3.23*
N × P		3.82**	0.68	2.19	2.99*	4.79**

NAE – nitrogen agronomic efficiency; NRE – nitrogen recovery efficiency; NPFP – nitrogen partial factor productivity; NCR – nitrogen contribution rate; NHI – nitrogen harvest index. Data are means ± standard deviation (n = 3); means within the same column followed by different letters are significantly different between treatments (P < 0.05, Duncan's test). *P < 0.05; **P < 0.01

differently to the way nutrients are supplied in different nutrient environments. Rice can adjust gene expression through changes in intracellular nutrient conditions according to different nutritional environments during each growth period to achieve N and P balance (Vinod and Heuer 2012). The application of middle-P and high-P can increase the dry matter accumulation at the full heading stage of crops in all N environments. However, high P limited the output and transport of dry matter in the stem and sheath, which also limited the efficient transfer of photosynthetic products to grains. The application of low-P cannot significantly increase the dry matter accumulation at the full heading stage in the none-N and low N treatments, but low P promoted the output and transport of stem and sheath dry matter from the full heading stage to the mature stage, and at the same time ensured high nutrition elemental absorption. Reduce input costs while ensuring high dry matter accumulation and yield benefits. The positive effect of high N on the growth and development of rice was demonstrated by Zhao et al. (2020). Our research further suggests that there was a synergistic effect between high N conditions and increased application of P fertiliser on yield, and P2 ensured higher N fertiliser use efficiency by promoting dry matter accumulation and N uptake.

The current research showed that adding P fertiliser alone cannot improve rice growth and yield at none N level. Under the low-N, P1 treatment promoted the material transport process and increased the nutrient uptake to increase yield. We conclude that the high N condition and the increased application of P fertiliser had a synergistic effect on the formation of crop yield. When the N application rate was higher than 150 kg/ha (N2 and N3), the P2 level recorded the highest N use efficiency. Combined with the experimental research results of rice production characteristics in this region, it is believed that under low N conditions, a P application rate of 13.2 kg/ha, and high N conditions, a P application rate of 26.4 kg/ha is more suitable for high yield of rice.

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REFERENCES

An N., Wei W.L., Qiao L., Zhang F.S., Christie P., Jiang R.F., Dobermann A., Goulding K.W.T., Fan J.L., Fan M.S. (2018): Agronomic and environmental causes of yield and nitrogen use efficiency gaps in Chinese rice farming systems. European Journal of Agronomy, 93: 40–49.

Cassman K.G., Dobermann A., Walters D.T., Yang H.S. (2003): Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 28: 315–358.

Che S.G., Zhao B.Q., Li Y.T., Yuan L., Lin Z.A., Hu S.W., Shen B. (2016): Nutrient uptake requirements with increasing grain yield for rice in China. Journal of Integrative Agriculture, 15: 907–917.

Chin J.H., Lu X.C., Haefele S.M., Gamuyao R., Ismail A., Wissuwa M., Heuer S. (2009): Development and application of gene-based markers for the major rice QTL phosphorus uptake 1. Theoretical and Applied Genetics, 120: 1073–1086.

Du M., Zhang W.Z., Gao J.P., Liu M.Q., Zhou Y., He D.W., Zhao Y.Z., Liu S.M. (2022): Improvement of root characteristics due to nitrogen, phosphorus, and potassium interactions increases rice (*Oryza sativa* L.) yield and nitrogen use efficiency. Agronomy, 12: 23.

Duncan E.G., O'Sullivan C.A., Roper M.M., Biggs J.S., Peoples M.B. (2018a): Influence of co-application of nitrogen with phosphorus, potassium and sulphur on the apparent efficiency of nitrogen fertiliser use, grain yield and protein content of wheat: review. Field Crops Research, 226: 56–65.

Duncan E.G., O'Sullivan C.A., Roper M.M., Palta J., Whisson K., Peoples M.B. (2018b): Yield and nitrogen use efficiency of wheat increased with root length and biomass due to nitrogen, phosphorus, and potassium interactions. Journal of Plant Nutrition and Soil Science, 181: 364–373.

Fageria N.K. (2001): Nutrient management for improving upland rice productivity and sustainability. Communications in Soil Science and Plant Analysis, 32: 2603–2629.

Gautam P., Lal B., Panda B.B., Bihari P., Chatterjee D., Singh T., Nayak P.K., Nayak A.K. (2021): Alteration in agronomic practices to utilize rice fallows for higher system productivity and sustainability. Field Crops Research, 260: 108005.

Hou W.F., Khan M.R., Zhang J.L., Lu J.W., Ren T., Cong R.H., Li X.K. (2019): Nitrogen rate and plant density interaction enhances radiation interception, yield and nitrogen use efficiency of mechanically transplanted rice. Agriculture, Ecosystems and Environment, 269: 183–192.

Hu B., Chu C.C. (2020): Nitrogen-phosphorus interplay: old story with molecular tale. New Phytologist, 225: 1455–1460.

Huang M., Liu Y., Chen J.N., Cao F.B. (2022): The difference method is not necessarily reliable for comparing the nitrogen use efficiency of hybrid rice cultivars with different tolerance to low nitrogen conditions. Crop and Environment, 1: 168–172.

Ke J., Xing X.M., Li G.H., Ding Y.F., Dou F.G., Wang S.H., Liu Z.H., Tang S., Ding C.Q., Chen L. (2017): Effects of different controlled-release nitrogen fertilisers on ammonia volatilisation, nitrogen use efficiency and yield of blanket-seedling machine-transplanted rice. Field Crops Research, 205: 147–156.

Long X.E., Yao H.Y. (2020): Phosphorus input alters the assembly of rice (*Oryza sativa* L.) root-associated communities. Microbial Ecology, 79: 357–366.

Lu D.J., Song H., Jiang S.T., Chen X.Q., Wang H.Y., Zhou J.M. (2019): Managing fertiliser placement locations and source types to improve rice yield and the use efficiency of nitrogen and phosphorus. Field Crops Research, 231: 10–17.

Ma J.Y., Chen T.T., Lin J., Fu W.M., Feng B.H., Li G.Y., Li H.B., Li J.C., Wu Z.H., Tao L.X., Fu G.F. (2022): Functions of nitrogen, phosphorus and potassium in energy status and their influences on rice growth and development. Rice Science, 29: 166–178.

Meena A.K., Singh D.K., Pandey P.C., Nanda G. (2019): Dynamics of dry matter and nitrogen distribution in transplanted rice on mollisols. Journal of Plant Nutrition, 42: 749–758.

Ntanos D.A., Koutroubas S.D. (2002): Dry matter and N accumulation and translocation for Indica and Japonica rice under Mediterranean conditions. Field Crops Research, 74: 93–101.

Oesper R.E. (1934): Kjeldahl and the determination of nitrogen. Journal of Chemical Education, 11: 457–462.

Pan J.F., Liu Y.Z., Zhong X.H., Lampayan R.M., Singleton G.R., Huang N.R., Liang K.M., Peng B.L., Tian K. (2017): Grain yield, water productivity and nitrogen use efficiency of rice under different water management and fertilizer-N inputs in South China. Agricultural Water Management, 184: 191–200.

Rakotoson T., Six L., Razafimanantsoa M.P., Rabeharisoa L., Smolders E. (2014): Effects of organic matter addition on phosphorus availability to flooded and nonflooded rice in a P-deficient tropical soil: a greenhouse study. Soil Use and Management, 31: 10–18.

Ren D.Y., Li Y.F., He G.H., Qian Q. (2019): Multifloret spikelet improves rice yield. New Phytologist, 225: 2301–2306.

Shahane A.A., Shivay Y.S., Kumar D., Prasanna R. (2018): Interaction effect of nitrogen, phosphorus, and zinc fertilization on growth, yield, and nutrient contents of aromatic rice varieties. Journal of Plant Nutrition, 41: 2344–2355.

Vinod K.K., Heuer S. (2012): Approaches towards nitrogen- and phosphorus-efficient rice. AoB Plants, 2012: pls028.

Wang H.X., Lu Y., Xu J.L., Liu X.J., Sheng L.X. (2021): Effects of additives on nitrogen transformation and greenhouse gases emission of co-composting for deer manure and corn straw. Environmental Science and Pollution Research, 28: 13000–13020.

Yang G.T., Nabi F., Sajid S., Kaleri A.R., Jakhar A.M., Cheng L., Raspor M., Muhammad N., Ma J., Hu Y.G. (2021): Response of root development and nutrient uptake of two chinese cultivars of hybrid rice to nitrogen and phosphorus fertilization in Sichuan Province, China. Molecular Biology Reports, 48: 8009–8021.

https://doi.org/10.17221/420/2022-PSE

Yang G.T., Liu R., Ma P., Chen H., Zhang R.P., Wang X.C., Li Y.Y., Hu Y.G. (2022): Effects of nitrogen and phosphorus regulation on plant type, population ecology and sheath blight of hybrid rice. Plants (Basel), 11: 2306.

Ye T.H., Li Y.W., Zhang J.L., Hou W.F., Zhou W.F., Lu J.W., Xing Y.Z., Li X.K. (2019): Nitrogen, phosphorus, and potassium fertilization affects the flowering time of rice (*Oryza sativa* L.). Global Ecology and Conservation, 20: e00753.

Ye Y.S., Liang X.Q., Chen Y.X., Liu J., Gu J.T., Guo R., Li L. (2013): Alternate wetting and drying irrigation and controlled-release nitrogen fertilizer in late-season rice. Effects on dry matter accumulation, yield, water and nitrogen use. Field Crops Research, 144: 212–224.

Zhang D., Wang H.Y., Pan J.T., Luo J.F., Liu J., Gu B.J., Liu S., Zhai L.M., Lindsey S., Zhang Y.T., Lei Q.L., Wu S.X., Smish P., Liu H.B. (2018): Nitrogen application rates need to be reduced for half of the rice paddy fields in China. Agriculture, Ecosystems and Environment, 265: 8–14.

Zhang Y., Zhang C.C., Yan P., Chen X.P., Yang J.C., Zhang F.S., Cui Z.L. (2013): Potassium requirement in relation to grain yield and genotypic improvement of irrigated lowland rice in China. Journal of Plant Nutrition and Soil Science, 176: 400–406.

Zhao C.K., Yang G.T., Wang H.N., Muhammad N., Wang X.C., Ma J., Hu Y.G., Zhang R.P. (2020): Nitrogen fertilizer changed the temperature and humidity of the rice population and aggravated the development of sheath blight. Pakistan Journal of Science, 57: 1481–1492.

Zheng W.K., Liu Z.G., Zhang M., Shi Y.F., Zhu Q., Sun Y.B., Zhou H.Y., Li C.L., Yang Y.C., Geng J.B. (2017): Improving crop yields, nitrogen use efficiencies, and profits by using mixtures of coated controlled-released and uncoated urea in a wheat-maize system. Field Crops Research, 205: 106–115.

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