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Different micro-climate response of indica rice population to nitrogen fertilizer

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ABSTRACT

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Field experiment was carried out from 2014 to 2016 to clarify the micro-climate response of indica rice population to nitrogen fertilizer. R498, R816 and R499 were used as representatives of drooping panicle, semi-erect panicle and erect panicle indica rice, respectively and 3 nitrogen fertilizer levels (N0 – 0 kg N/ha; N1 – 150 kg N/ha; N2 – 150 kg/ha) were set for each panicle of indica rice. Results showed that the erect panicle indica rice (R499) improved the environment of temperature, relative humidity and light of rice population under heavy nitrogen fertilizer, and built a healthier micro-climate environment for rice population, especially at the middle position of rice population. Comparing with drooping panicle indica rice (R498), erect panicle indica rice performed better under heavy nitrogen fertilizer, with a higher micro-climate response index to nitrogen fertilizer at middle and lower position in rice population. In comparison of R498, the yield of R499 increased by 0.10–0.11 t/ha under N1 treatment, while it increased by 0.93–0.96 t/ha under N2 treatment; thus, the suggestion for farmers is to plant erect panicle indica rice in heavy fertilizer area or to use more fertilizer in moderate fertilizer area.

Keywords: *Oryza sativa* L.; macronutrient; fertilization; microenvironment; canopy; climatic conditions

Improved nitrogen (N) responsiveness and lodging resistance of high-yielding rice cultivars resulted in overuse of fertilizers, particularly N fertilizers (Peng et al. 2002), as farmers tended to apply a higher amount of N fertilizer than required to realize high yield potential. Thus, global N consumption increased approximately 8-fold from 1961 to 2013, of which China accounted for approximately 8% in 1961 and 35% in 2013 (Wang and Peng 2017). Higher nitrogen fertilizer not only increased the tiller number, biomass, leaf area index (LAI), canopy etcetera (Horie et al. 1997), but also brought a negative effect on micro-climate health of rice population (Katsura et al. 2008). Generally light and air permeability of rice plots decreased while temperature and relative humidity of rice plots became higher under higher nitrogen fertilizer levels, which make the nitrogen using efficiency decreased due to the wide spread of diseases and insect pests, such as lodging, rice blast and *Cnaphalocrocis medinalis* (Guenée) etc. (He 2009).

Panicle type and plant type is a key plant architecture that can be used by rice breeders and farmers

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to improve the micro-climate under higher level of nitrogen fertilizer. The accumulated knowledge showed that panicle erectness cultivars improve population structure and photoreception posture, reduce radiation loss from population reflectance, and promote population gas change, consequently leading to the increase of rice yield in heavy fertilizer areas (Huang et al. 2009). In contrast, drooping panicle rice has been reported to lodge more easily (Gao et al. 1999). Tang et al. (2017) reported that the correlation between harvest index and plant height was not significant in erect panicle rice, whatever the nitrogen and density. Most agricultural scientists believed that qualities of a rice plant's type and canopy structure play key roles in increasing its production and improving its quality (Zhou et al. 2009, Zhu et al. 2010). Therefore, more and more scientists in this area focus on the problem of optimizing phonotypical traits of rice in order to obtain ideal individuals with high or super-high production (Tang et al. 2017). Recently, series cultivars of japonica rice with improved traits, such as leaf morphology, panicle type, plant height and tiller angle, were cultivated and produced a higher yield level (Zhang et al. 2002, Chen et al. 2014).

However, few erect panicle indica rice cultivars have been used to improve the population health in heavy fertilizer area, such as Yangtze River basin. The objectives of this paper were to clarify the micro-climate response of erect panicle indica rice on nitrogen fertilizer and to provide experimental evidence that erect panicle indica rice can improve the population health in heavily fertilizer areas.

MATERIAL AND METHODS

Experiment and materials. The experiment was carried out in Mianyang, Sinchuan province from 2014 to 2016. From R498 (Shuhui498), its mutations R499 and R816 were obtained by the EMS (ethyl methanesulfonate) mutagenesis technique. The plant types of R498, R499 and R816 were similar while their panicle types are different. According to the panicle classification method reported by Xu et al. in 1990 and 2010, R498 was drooping panicle, R816 was semi-erect panicle and R499 was erect panicle.

Three nitrogen fertilizer levels (Table 1) were designed for R498, R816 and R499, respectively. The experiment was established as a split-plot design with fertilizer as the main factor, and rice panicle types as split plot factors. All experiments were established in 3 replicates with 27 plots of 5 m × 6.5 m. A cement buffer zone of 1 m width and 0.5 m depth was established for the main factor (fertilizer plots) to prevent nitrogen and water leakage from one plot to another plot. Phosphorous (P) and potassium (K) applied for each plot was the same with 39.5 kg P/ha and 99.6 kg K/ha, respectively.

Table 1. Nitrogen fertilizer (kg N/ha) applied for different treatments and different panicle types

	Panicle type	N0	N1	N2
R498	drooping panicle	0	150	300
R816	semi-erect panicle	0	150	300
R499	erect panicle	0	150	300

Sample and measurement

Rice yield. At maturity, five representative plants in each plot were harvested by cutting the plants at the soil surface. The harvested plants were dried naturally for a month and then the following values were measured: panicle number per plant (PN); spikelet number per panicle (SNP); spikelet fertility (SF, %); thousand-grain weight (GW, g); 3 m^2 of plants were harvested by hand to calculate the grain yield (GY, t/ha).

Micro-climate of rice population. The measurements of air temperature, relative humidity and luminous intensity in rice population were taken by sensors and rapid measurements, at the full heading day and the 20^{th} day after full heading in 2015 and 2016. Sensors were usually located at an 'upper' position in the canopy, which was defined as 4/5 of the total canopy height. For some measurements, sensors were also located at 'lower' position, defined as 1/5 of the total canopy height, or in 'middle' canopy position, defined as 1/2 of the total canopy height. Detailed information of sensors and recording equipment are provided in Table 2.

Statistical and analysis methods. Response of microenvironment on nitrogen fertilizer was calculated from Eqs. 1–4:

$$RIT_n\mathcal{E} = \frac{T_n\mathcal{E} - T_{n-1}\mathcal{E}}{T_{n-1}\mathcal{E}} \quad n \geq 1,\ \varepsilon = \text{U, M and L} \qquad (1)$$

$$RIH_n\mathcal{E} = \frac{H_n\mathcal{E} - H_{n-1}\mathcal{E}}{H_{n-1}\mathcal{E}} \quad n \geq 1,\ \varepsilon = \text{U, M and L} \qquad (2)$$

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Table 2. Detailed information on sensors and equipment used for experiment

	Product model	Resolution	Accuracy	Range
Temperature (°C)	TP1000	0.1	± 0.5	–25–85
Humidity (%)	TP1000	0.1	± 0.3	0–99.9
Luminometer (lux)	TASI-8720	1	< 10 000	1000–200 000
Shielder	inner diameter: 20 mm; outer diameter: 30 mm			

$$RIL_n\mathcal{E} = \frac{L_n\mathcal{E} - L_{n-1}\mathcal{E}}{L_{n-1}\mathcal{E}} \quad n \geq 1,\ \varepsilon = \text{U, M and L} \quad (3)$$

$$RIC_n\mathcal{E} = \left|\frac{RIT_n\mathcal{E} \times 5 + RIH_n\mathcal{E} \times 5 + RIL_n\mathcal{E}}{s}\right| \quad n \geq 1,\ \varepsilon = \text{U, M and L} \quad (4)$$

Where: $RIT_n\varepsilon$, $RIH_n\varepsilon$, $RIL_n\varepsilon$ – relative response index of temperature, humidity and luminous intensity of rice population to nitrogen fertilizer; ε – position of sensors in rice population; U – upper position; M – middle position; L – lower position; T_n, H_n and L_n – temperature, humidity and luminous intensity of rice population at fertilizer level *n*; $T_{n–1}$, $H_{n–1}$ and $L_{n–1}$ – temperature, humidity and luminous intensity of rice population at fertilizer level *n*–1; *n* – fertilizer level of nitrogen; *n* = 0 – no fertilizer used; *n* = 1 – lower fertilizer used for rice with 150 kg/ha pure nitrogen; *n* = 2 – higher fertilizer used for rice with 300 kg/ha pure nitrogen. $RIC_n\varepsilon$ – comprehensive response index of micro-climate to nitrogen fertilizer *n*; S – total number of samples. Higher $RIC_n\varepsilon$ – better micro-climate response of rice population on nitrogen fertilizer.

RESULTS

Response of temperature on nitrogen fertilizer. On the full heading day, under N1 treatment, response index of temperature on fertilizer at upper position performed an insignificant difference among different panicle types (Table 3, RIT_1U); however under N2 treatment, it showed a significant difference among different panicle types (Table 3, RIT_2U). Response index of temperature on fertilizer of R499 was significantly lower than R498, either at lower fertilizer level (Table 3, RIT_1M, RIT_1L) or under higher fertilizer level (Table 3, RIT_2M, RIT_2L). On the 20th day after full heading, response of temperature to nitrogen fertilizer was impacted not only by position of rice population but it was also influenced by rice panicle type. Response of temperature to nitrogen fertilizer of R498, R816 and R499 performed a significant difference not only under lower fertilizer level (Table 3, RIT_1U, RIT_1M, and RIT_1L) but also under higher fertilizer level (Table 3, RIT_2U, RIT_2M, and RIT_2L).

Response of relative humidity on nitrogen fertilizer. On the full heading day, under higher fertilizer level (N1–N2, Table 4), the response index of humidity on nitrogen fertilizer at middle position (RIH_2M) of R499 was significantly lower than R498; however under lower fertilizer level (N0–N1, Table 4), the response index of humidity on nitrogen fertilizer of R499 was significantly lower

Table 4. Response index of relative humidity on nitrogen fertilizer for different panicle types on the 20th day after full heading

		N0–N1			N1–N2		
		RIH_1U	RIH_1M	RIH_1L	RIH_2U	RIH_2M	RIH_2L
Full heading day	R498	0.023^a	0.096^a	0.112^a	0.026^b	0.063^a	0.046^a
	R816	0.013^b	0.089^a	0.128^a	0.062^a	0.055^b	0.048^a
	R499	0.018^{ab}	0.080^b	0.091^b	0.025^b	0.054^b	0.048^a
20th day after full heading	R498	0.017^b	0.064^a	0.010^b	–0.028^b	0.095^b	0.069^b
	R816	0.042^a	0.063^a	0.044^a	–0.026^b	0.079^c	0.033^c
	R499	0.014^b	0.047^b	0.017^b	–0.008^a	0.108^a	0.077^a

RIH_1U, RIH_1M, RIH_1L – response index of relative humidity on nitrogen fertilizer at upper, middle and lower position under N1 treatment, respectively; RIH_2U, RIH_2M, RIH_2L – response index of relative humidity on nitrogen fertilizer at upper, middle and lower position under N2 treatment, respectively. Different letters indicate statistically significant at $P \leq 0.05$

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than R498 not only at middle position (RIH_1M) but also at lower position (RIH_1L). On the 20th day after full heading, under lower fertilizer level (N0–N1, Table 4), the response index of humidity on nitrogen fertilizer at middle position (RIH_1M) of R499 was significantly higher than for R498 and R816; however, under higher fertilizer level (N1–N2, Table 4) the response index of humidity on nitrogen fertilizer of R499 was significantly higher than for R498 and R816, not only at upper position (RIH_2U) but also at middle (RIH_2M) and lower position (RIH_2L).

Response of luminous intensity to nitrogen fertilizer. Comparing with other panicle types, R499 had the highest luminous intensity at upper, middle and lower position. Under N2 treatments and comparing with R498, the luminous intensity of R816 on the full heading day increased by 1129, 86 and 31 lx at upper, middle and lower positon, respectively; however, it increased by 333, 1760 and 102 lx, respectively on the 20th day after full heading. Under N2 treatment and comparing with R498, the luminous intensity of R499 on the full heading day increased by 3367, 194 and 49 lx at upper, middle and lower position, respectively; however it increased 2785, 2240 and 361 lx, respectively, on the 20th day after full heading. Under higher nitrogen fertilizer treatment, R499 improved the light environment of upper and middle position of rice population, which is better to the process of photosynthesis of rice population.

Comprehensive response of micro-climate to nitrogen fertilizer. On the full heading day, the comprehensive response index of micro-climate on nitrogen fertilizer (RIC) of R498 and R816 gradually decreased from upper to lower position and from N1 to N2. RIC value of R499 also performed a declining trend from upper to lower position when fertilizer increased from N0 to N1; however RIC at upper position was lower than in middle and lower position when fertilizer increased from N1 to N2 (Figure 1).

On the 20th day after full heading, RIC of R498 still performed a declining trend from upper to lower position when fertilizer ranged from N0 to N1. When fertilizer increased from N1 to N2, R498, R816 and R499 all showed a lower RIC at upper position, comparing with that at middle and lower position. This result indicated that micro-climate of R499 has a better response to higher fertilizer level at middle than upper and lower position. Comparing with other two panicle types, RIC at middle and lower position of R499 was significantly higher, which means that the micro-climate response of R499 performed better than other two panicle types when higher fertilizer was used.

Yield and its components of different panicle types. Comparing with N0, panicle number per plant of R498, R816 and R499 increased by 1.215, 1.575 and 1.302 under N1 fertilizer treatment; while under N2 treatment it increased by 0.435, 0.580 and 0.935, respectively. When fertilizer rose

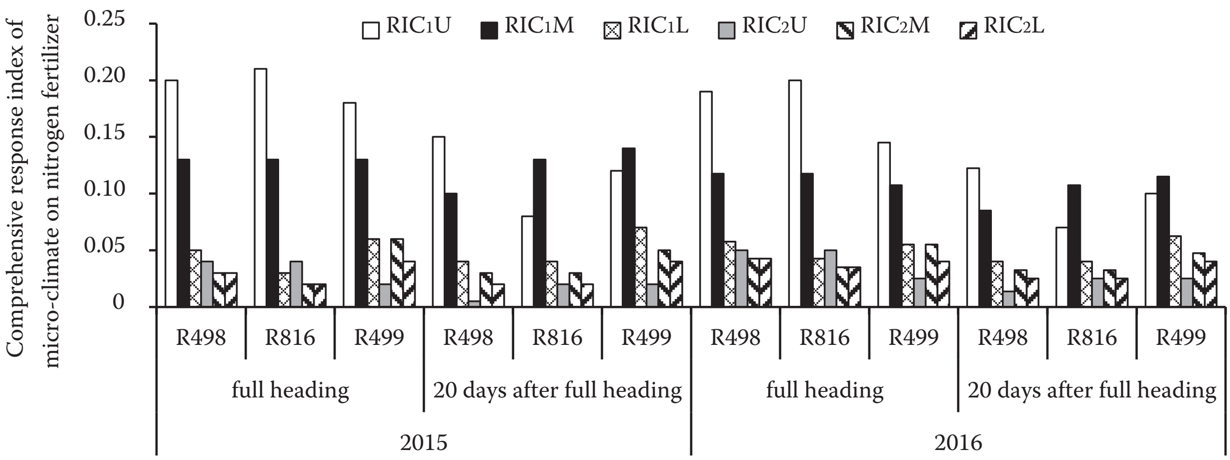

Figure 1. Comprehensive response of micro-climate to nitrogen fertilizer for different panicle types at different positions from 7:00 to 19:00 on the full heading day and on the 20th day after full heading. RIC_1U, RIC_1M, RIC_1L – the comprehensive response index of micro-climate on nitrogen fertilizer at upper, middle and lower position under N1 treatment, respectively; RIC_2U, RIC_2M, RIC_2L – the comprehensive response index of micro-climate on nitrogen fertilizer at upper, middle and lower position under N_2 treatment, respectively

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Table 5. Grain yield and its components of different panicle types under different fertilizer treatments in 2015 and 2016

Variety	Treatment	PN		SNP		SF (%)		GW (g)		GY (t/ha)	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
N0	R498	4.33^{ab}	4.31^{ab}	294.77^{a}	291.72^{ab}	84.03^{a}	82.10^{ab}	33.16^{a}	33.08^{a}	7.45^{a}	7.58^{a}
	R816	4.00^{b}	3.98^{b}	249.75^{b}	244.61^{b}	74.72^{b}	73.80^{b}	31.10^{a}	31.02^{a}	5.61^{b}	5.58^{b}
	R499	4.67^{a}	4.51^{a}	286.00^{a}	281.32^{a}	88.50^{a}	87.90^{a}	33.03^{a}	33.11^{a}	8.23^{a}	8.11^{a}
N1	R498	6.67^{a}	4.40^{b}	256.47^{a}	248.27^{a}	87.22^{a}	88.75^{a}	33.20^{a}	33.14^{a}	8.88^{a}	8.60^{a}
	R816	6.33^{a}	4.80^{ab}	240.13^{a}	250.39^{ab}	79.28^{b}	86.59^{a}	31.12^{a}	31.21^{b}	8.79^{a}	8.50^{a}
	R499	6.78^{a}	5.00^{a}	267.56^{a}	240.26^{a}	89.07^{a}	90.20^{a}	33.51^{a}	33.24^{a}	8.99^{a}	8.70^{a}
N2	R498	6.93^{ab}	5.81^{ab}	277.08^{ab}	278.01^{ab}	77.73^{a}	78.35^{a}	33.69^{b}	33.21^{b}	9.38^{b}	9.35^{b}
	R816	6.67^{b}	5.62^{b}	248.01^{b}	246.02^{b}	74.06^{a}	74.12^{a}	31.29^{c}	31.31^{c}	9.19^{b}	9.04^{b}
	R499	7.33^{a}	6.32^{a}	268.45^{a}	269.32^{a}	79.24^{a}	80.31^{a}	34.46^{a}	34.28^{a}	10.31^{a}	10.21^{a}

PN – panicle number per plant; SNP – spikelet number per panicle; SF – spikelet fertility; GW – thousand-grain weight; GY – grain yield; N0 – 0 kg N/ha; N1 – 150 kg N/ha; N2 – 150 kg/ha

from N0 to N1, spikelet fertility of R498, R816 and R499 performed a rising trend with the increasing amount of nitrogen fertilizer. Spikelet fertility of R498, R816 and R499 increased by 4.92, 8.67 and 1.43, respectively, when fertilizer increased from N0 to N1 (Table 5). However, spikelet fertility decreased when fertilizer increased from N1 to N2. Comparing with N1, spikelet fertility of R498, R816 and R499 under N2 treatment decreased by 9.94, 8.84 and 9.86, respectively. With the increasing amount of nitrogen fertilizer, thousand-grain weight of R498, R816 and R499 all performed a rising trend from N0 to N1 and from N1 to N2. When nitrogen fertilizer ranged from N0 to N1, thousand-grain weight of R498, R816 and R499 increased by 0.050, 0.105 and 0.305 g, respectively; it increased by 0.280, 0.135 and 0.995 g, respectively, when fertilizer increased from N1 to N2. Under heavy nitrogen fertilizer, R499 was easier to get higher thousand-grain weight. Under N1 treatment, the yield differences of R498, R816 and R499 were insignificant, while the values for R499 were significantly higher than for R498 and R816 under N2 treatment. This result indicates that R499 is better for heavy nitrogen fertilizer.

DISCUSSION

The erect panicle rice, created from a mutation of *DEP1* (*EP*, *qPE9-1*) gene (Wang et al. 2009, Xu et al. 2010, 2015, Yan et al. 2007), has an optimized canopy structure (Zhou et al. 2009, Zhu et al. 2010). Comparing with other two panicle types, R499 got higher luminous intensity at upper, middle and lower position under N2 treatment. When fertilizer increased from N1 to N2, relative response index of luminous intensity to nitrogen fertilizer at middle and lower position of R499 was significantly higher than that of R498. These results indicates that R499 improved the luminous environment at middle and lower position and improved the photosynthetic efficiency of R499.

Temperature is one of the key factors to affect the enzyme activity of photosynthesis, and also impacts opening and closure of stoma on leaves (Cripps 1987, Jurik and Van 2004). This study showed that on the 20th day after full heading and compared with R498, the temperature at upper and middle position of R499 was significantly lower. This might be benefit to the process of photosynthesis during higher temperature period (11:00 to 13:00). An increase of nitrogen fertilizer caused a significant decrease of the rice plot temperature at middle position, and also caused a relative humidity increase at middle and lower position. Compared with R498, the relative humidity at upper and middle position of R499 decreased by 3.53% and 3.20%, respectively, under N2 fertilizer treatment. With heavy nitrogen fertilizer, the population of R499 got lower relative temperature and lower relative humidity, which is better to build a healthy micro-climate for rice growth.

Tang et al. (2017) proved that *DEP1* also enhanced the harvest index of erect panicle japonica rice at the moderate levels of nitrogen fertilizer. Comparing with other two panicle types, a comprehensive response index of micro-climate on nitrogen fertilizer at middle and lower position of

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R499 was significantly higher under N2 treatment. When fertilizer increased from N1 to N2 (heavy fertilizer), grain yield of R499 increased by 1.415 t/ha, which was significantly higher than R816 (0.470 t/ha) and R498 (0.625 t/ha). This result indicated that erect panicle indica rice can more easily adapt to the heavy nitrogen fertilizer environment than semi-erect type and drooping type.

In conclusion, erect panicle indica rice (R499) improved the environment of temperature, relative humidity and light of rice population under heavy nitrogen fertilizer, and built a healthier micro-climate environment for rice population, especially at middle position of rice population.

Comparing with drooping panicle indica rice (R498), the erect panicle indica rice performed better under heavy nitrogen fertilizer (N1 to N2). So the suggestion for farmers is to plant erect panicle indica rice in heavy fertilizer area or use more fertilizer in moderate fertilizer area.

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