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不同氮素利用效率基因型水稻氮素积累与转移的特性

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摘 要: 选用氮素利用高效型和低效型具有代表性的 12 个粳稻基因型，研究水稻氮素积累、转移特性的差异及其与氮素利用效率的相互关系。结果表明，有效分蘖临界叶龄(N-n)、抽穗和成熟期，氮高效类型水稻的氮素积累量极显著高于氮低效类型，而拔节期差异不明显。水稻氮素的阶段性积累量，除(N-n)至拔节阶段，氮高效类型水稻极显著低于氮低效类型外，其余各阶段氮高效类型水稻的氮积累量均极显著高于氮低效类型。水稻氮素的阶段性积累率，移栽至(N-n)和(N-n)至拔节阶段氮低效类型水稻显著大于氮高效类型，而在拔节至抽穗和抽穗至成熟阶段则表现出相反的趋势。抽穗前的氮素转移量和转移率，氮高效类型水稻显著或极显著大于氮低效类型，而抽穗前氮对籽粒的贡献率，氮高效类型极显著低于氮低效类型。氮高效类型水稻具有在(N-n)前氮素适度积累，(N-n)后至抽穗阶段，氮素的有效积累高而无效积累弱的特点。因此至抽穗期，氮高效类型水稻的氮素积累量大于氮低效类型，具有较高的氮素转移量和转移率。但由于氮高效类型水稻在抽穗以后仍具有较强的氮素积累能力，因此其抽穗前氮对籽粒的贡献率相对低于氮低效类型。

关键词: 水稻; 氮素利用效率; 氮素积累; 氮素转移; 相关性

Characteristics of N Accumulation and Translocation in Rice Genotypes with Different N Use Efficiencies

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Abstract: N is yet the most important and largest input required in rice production although over use of N causes so many environment problems. N use efficiency is varied in different rice genotypes. Therefore it is necessary to identify the physiological mechanism of N absorption and utilization in different rice genotypes in order to increase N use efficiency through rice cultivar improvement. In this research, field experiment with 225 kg ha^{-1} N fertilizer application and twelve rice genotypes (6 N-efficient and 6 N-low-efficient) selected from 120 rice cultivars grown in Yangzhou during 2004 and 2005 were carried out in 2006 on the farm of Yangzhou University, Jiangsu province, China. Relationship between N use efficiency and indexes of rice N accumulation and translocation was analyzed. At the three growth stages including critical stage of productive tillering, heading, and maturing, the amount of N accumulation of N-efficient rice was obviously higher than that of N-low-efficient genotypes while at the stage of elongating, there was no significant difference in N accumulation between the two rice genotypes. In order to analyze the N accumulation progress of rice genotypes with different N use efficiency, the growth was also divided into four phases including from transplanting to critical stage of productive tillering, from critical stage of productive tillering to elongating, from elongating to

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heading and from heading to maturing. Results revealed that the amount of N accumulation of N-efficient genotypes was significantly higher than that of N-low-efficient genotypes during all growth phases except the phase from critical stage of productive tillering to elongating, at which the amount of N accumulation of N-efficient genotypes was significantly lower than that of N-low-efficient genotypes. The percentage in N accumulation of N-efficient genotypes was higher than that of N-low-efficient genotypes during the growth phases from elongating to heading and from heading to maturing while it showed the reversed trend during the phases from transplanting to critical stage of productive tillering and from the critical stage of productive tillering to elongating. The amount and the efficiency of N translocation before heading were obviously higher in N-efficient genotypes than those in N-low-efficient genotypes. On the contrary, the contribution rate of transferred N to the total N of rice grain at maturity was significantly lower in N-efficient genotypes than that in N-low-efficient genotypes. For N efficient genotypes, the amount of N accumulation before the critical stage of productive tillering was modest. And during the phase from the critical stage of productive tillering to heading, its N accumulation of usefulness was large while the N accumulation of uselessness was few. Therefore, till the stage of rice heading, the amount of N accumulation of N-efficient genotypes was obviously higher than that of N-low-efficient genotypes. And the amount and the efficiency of N translocation before heading of N-efficient genotypes were also higher than that of N-low-efficient genotypes. Because of the strong ability of N accumulation of N-efficient genotypes after heading, its contribution rate of transferred N to the total N of rice grain at maturity was relatively lower than that of N-low-efficient genotypes before heading.

Keywords: Rice; N use efficiency; N accumulation; N translocation; Correlation

氮肥投入是保证水稻稳产丰产的重要措施[1]，但是氮肥的过量施用在破坏生态环境的同时也威胁到人类的健康[2-3]。自 1939 年 Harvey 首次报道玉米不同品种在吸收利用氮素方面存在差异之后,水稻对氮素吸收利用的基因型差异也已为国内外众多科学家所证实[4-6]。水稻在生长过程中，其根系吸收的氮素在满足自身生长的同时运输至地上部还原同化，用于器官建成和产量形成。因此，水稻对氮素的吸收是决定其最终对氮素利用情况的重要前提。本研究于 2004 年和 2005 年对 120 份水稻基因型在 4 种不同施氮水平处理下(0、低、中、高)氮素利用效率分类、评价的基础上，2006 年从长江中下游地区应用较广的迟熟中粳和早熟晚粳中选择氮素利用高效型与低效型的代表性品种，系统研究其氮素积累与转移特性的差异，以期揭示水稻氮素利用基因型差异机制的形成，同时也为各氮效率类型品种在生产中因种因时施氮提供理论依据。

1 材料与方法

1.1 供试品种

依据 2004—2005 年的研究分类与评价，选取迟熟中粳中氮素利用高效型品种 9 优 418、武育粳 3 号、扬粳 9538，低效型品种农垦 57、武农早、郑稻 5 号，早熟晚粳中氮素利用高效型品种 86 优 8 号、武粳 15、泗优 422，早熟晚粳氮低效型品种镇稻 196、香粳 20-18、T1-56 共 12 个水稻基因型。

1.2 试验设计

试验于 2006 年在扬州大学农学院试验农场进行。前茬为小麦，土质为沙壤土，地力中等，土壤含全氮 0.13%、碱解氮 90.5 mg kg^{-1}、速效磷 35.6 mg kg^{-1}、速效钾 87.9 mg kg^{-1}。 采用裂区设计，以施氮(纯氮)水平为主区，设对照 N0(不施氮), N1(225 kg hm^{-2}) 2 个施氮水平；品种为裂区，裂区面积 15 m^2，重复 3 次。小区间做埂隔离，并用塑料薄膜覆盖埂体，保证各小区单独排灌。5 月 13 日播种, 6 月 12 日移栽，栽插密度为 27 万穴 hm^{-2} (14.4 cm×26.0 cm)。常规稻双本栽插，杂交稻单本栽插。氮肥基肥∶蘖肥∶穗肥=2.5∶2.5∶5.0，其中穗肥分别于倒 4 叶和倒 2 叶时期施入。每公顷分别以过磷酸钙和氯化钾的形式基施 P_2O_5 150 kg、K_2O 150 kg。其他管理措施统一按常规栽培要求实施。

1.3 测定内容与分析方法

分别于有效分蘖临界叶龄期、拔节期、抽穗期、成熟期定点调查群体茎蘖数(成熟期为有效穗数)，各处理取有代表性植株 4 穴。考察地上部性状后，分茎鞘、叶片和穗测定不同部位及全株干物重、含氮率。

采用 H_2SO_4-H_2O_2 消化，半微量凯氏定氮法测定氮素[7]。

氮肥利用效率=(施氮区植株总吸氮量－空白区植株总吸氮量)/施氮量×100

灌浆期茎叶氮素表观转移量=抽穗期茎叶鞘氮素积累量－成熟期茎叶鞘氮素积累量

灌浆期茎叶氮素表观转移率=(灌浆期茎叶氮素表观转移量/抽穗期茎叶鞘氮素积累量)×100

灌浆期转移的氮对籽粒的贡献率=(灌浆期茎叶氮素表观转移量/成熟期籽粒氮积累量)×100

各水稻基因型的氮素利用效率及产量见文献[8]。采用唐启义的 DPS 数据处理系统统计分析数据。

2　结果与分析

2.1　水稻氮素利用效率与产量的差异

数据及相关结果参见文献[8]。

2.2　不同氮效率类型水稻氮素积累量的差异

表 1 表明, 各生育时期, 水稻的氮素积累量存在显著的基因型差异。其中, 在有效分蘖临界叶龄期、抽穗和成熟期, 氮高效类型水稻的氮素积累量极显著大于氮低效类型。在拔节期, 氮高效类型水稻的氮素积累量与氮低效类型互有高低。两种生育类型表现出相同的趋势。有效分蘖临界叶龄期、拔节期、抽穗期和成熟期的氮素积累量的平均值, 氮高效类型均大于氮低效类型, 其中迟熟中粳分别高 6.71%、0.67%、16.09%和 23.68%, 早熟晚粳分别高 6.46%、0.21%、12.11%和 18.45%。

2.3　不同氮效率类型水稻氮素阶段性积累量的差异

表 2 表明, 移栽至有效分蘖临界叶龄、拔节至抽穗和抽穗至成熟阶段, 氮高效类型水稻的氮素积累量均极显著大于氮低效类型, 其中, 迟熟中粳分别高 6.71%、29.57%和 78.83%, 早熟晚粳分别高 6.46%、21.94%和 57.85%。有效分蘖临界叶龄至拔节阶段, 氮高效类型水稻的氮素积累量均极显著低于氮低效类型, 其中, 迟熟中粳低 5.06%, 早熟晚粳低 6.19%。两种生育类型表现一致的趋势。

2.4　不同氮效率类型水稻氮素阶段性积累率的差异

表 3 表明, 移栽至有效分蘖临界叶龄和有效分蘖临界叶龄至拔节阶段, 氮高效类型水稻的氮素积累率极显著低于氮低效类型, 其中迟熟中粳分别低 13.71%和 23.32%, 早熟晚粳分别低 10.08%和 20.78%。拔节至抽穗和抽穗至成熟阶段, 氮高效类型水稻的氮素积累率显著或极显著高于氮低效类型, 其中迟熟中粳分别高 4.71%和 45.18%, 早熟晚粳分别高 2.93%和 33.23%。

2.5　不同氮效率类型水稻氮素转移特性的差异

表 4 表明, 就水稻灌浆期茎叶氮素表观转移量和转移率而言, 氮高效类型水稻极显著或显著大于氮低效类型水稻, 其中迟熟中粳分别高 20.06%和 4.80%, 早熟晚粳分别高 14.68%和 2.96%。而灌浆期转移的氮对籽粒的贡献率, 氮高效类型极显著低于

表 1　不同氮效率类型水稻氮素积累量的差异

Table 1　Diversity of N accumulation in rice types with different N use efficiencies(kg hm^{-2})

品种类型 Rice type	生育期 Grouth stage	基因型 Genotype	N-n	EG	HD	MT
LMMR	NLE	农垦 57 Nongken 57	26.68 Ff	55.76 Cc	118.20 Ff	131.20 Ee
		武农早 Wunongzao	28.49 Dd	58.04 Aa	125.90 Dd	142.09 Dd
		郑稻 5 号 Zhengdao 5	27.80 Ee	56.71 Bb	121.50 Ee	142.63 Dd
	NE	9 优 418　9 you 418	28.92 Cc	56.86 Bb	144.01 Aa	176.10 Aa
		武育粳 3 号 Wuyujing 3	29.25 Bb	56.90 Bb	138.90 Cc	166.64 Cc
		扬粳 9538 Yangjing 9538	30.36 Aa	57.88 Aa	141.51 Bb	171.69 Bb
EMLR	NLE	镇稻 196 Zhendao 196	31.11 Df	61.88 Bb	136.59 Ee	158.50 Cc
		香粳 20-18 Xiangjing 20-18	31.47 Ce	61.39 BCc	137.80 Dd	160.53 Cc
		T1-56	31.67 Cd	62.84 Aa	136.74 Ee	158.30 Cc
	NE	86 优 8 号 86 you 8	33.85 Ab	62.59 Aa	150.10 Cc	182.89 Bb
		武粳 15 Wujing 15	32.46 Bc	61.06 Cc	153.08 Bb	190.82 Aa
		泗优 422 Siyou 422	34.03 Aa	62.86 Aa	157.71 Aa	191.67 Aa

标以不同大、小写字母的数值分别具 1%和 5%显著差异; LMMR: 迟熟中粳; EMLR: 早熟晚粳; NIE: 氮低效型;NE: 氮高效型; N-n: 有效分蘖临界叶龄; EG:拔节; HD: 抽穗; MT: 成熟。

Values followed by a different letter are significantly different at 1% (capital) and 5% (small) probability levels, respectively. LMMR: late maturing medium Japonica rice; EMLR: early maturing late Japonica rice; NLE: N low-efficient; NE: N efficient; N-n: critical stage of productive tillering; EG: elongation; HD: heading; MT: maturing.

表 2 不同氮效率类型水稻氮素阶段性积累量的差异

Table 2 Diversity of period N accumulation in rice types with different N use efficiencies(kg hm^{-2})

品种类型 Rice type	生育期 Grouth stage	基因型 Genotype	TP-(N-n)	(N-n)-EG	EG-HD	HD-MT
LMMR	NLE	农垦 57 Nongken 57	26.68 Ff	29.09 ABb	62.43 Ee	13.00 Ef
		武农早 Wunongzao	28.49 Dd	29.55 Aa	67.87 Cc	16.19 De
		郑稻 5 号 Zhengdao 5	27.80 Ee	28.91 Bb	64.79 Dd	21.14 Cd
	NE	9 优 418 9 you 418	28.92 Cc	27.93 Cc	87.15 Aa	32.09 Aa
		武育粳 3 号 Wuyujing 3	29.25 Bb	27.65 Ccd	82.00 Bc	27.74 Bc
		扬粳 9538 Yangjing 9538	30.36 Aa	27.52 Cd	83.63 Bb	30.17 ABb
EMLR	NLE	镇稻 196 Zhendao 196	31.11 Df	30.77 Ab	74.71 Ee	21.90 Cc
		香粳 20-18 Xiangjing 20-18	31.47 Ce	29.92 Bc	76.40 Dd	22.73 Cc
		T1-56	31.67 Cd	31.17 Aa	73.89 Ef	21.56 Cc
	NE	86 优 8 号 86 you 8	33.85 Ab	28.75 Cd	87.51 Cc	32.78 Bb
		武粳 15 Wujing 15	32.46 Bc	28.60 Cd	92.02 Bb	37.74 Aa
		泗优 422 Siyou 422	34.03 Aa	28.83 Cd	94.85 Aa	33.96 Bb

标以不同大、小写字母的数值分别具 1%和 5%显著差异。缩写同表 1。

Values followed by a different letter are significantly different at 1% (capital) and 5% (small) probability levels, respectively. Abbreviations as in Table 1.

表 3 不同氮效率类型水稻氮素阶段性积累率的差异

Table 3 Diversity of period percentage of N accumulation in rice types with different N use efficiencies(%)

品种类型 Rice type	生育期 Grouth stage	基因型 Genotype	TP-(N-n)	(N-n)-EG	EG-HD	HD-MT
LMMR	NLE	农垦 57 Nongken 57	20.33 Aa	22.17 Aa	47.59 Bb	9.91 De
		武农早 Wunongzao	20.05 Bb	20.80 Bb	47.76 Bb	11.39 Dd
		郑稻 5 号 Zhengdao 5	19.49 Cc	20.27 Cc	45.42 Cc	14.82 Cc
	NE	9 优 418 9 you 418	16.42 Ee	15.86 Ee	49.49 Aa	18.22 Aa
		武育粳 3 号 Wuyujing 3	17.55 Dd	16.59 Dd	49.21 Aa	16.65 Bb
		扬粳 9538 Yangjing 9538	17.68 Dd	16.03 Ee	48.71 ABa	17.57 ABab
EMLR	NLE	镇稻 196 Zhendao 196	19.63 Ab	19.41 Aa	47.14 CDcd	13.82 Cc
		香粳 20-18 Xiangjing 20-18	19.60 Ab	18.64 Bb	47.60 BCDbc	14.16 Cc
		T1-56	20.01 Aa	19.69 Aa	46.68 Dd	13.62 Cc
	NE	86 优 8 号 86 you 8	18.51 Bc	15.72 Cc	47.85 BCb	17.93 ABb
		武粳 15 Wujing 15	17.01 De	14.99 Dd	48.22 Bb	19.78 Aa
		泗优 422 Siyou 422	17.75 Cd	15.04 Dd	49.49 Aa	17.72 Bb

标以不同大、小写字母的数值分别具 1%和 5%显著差异。缩写同表 1。

Values followed by a different letter are significantly different at 1% (capital) and 5% (small) probability levels, respectively. Abbreviations as in Table 1.

氮低效类型，其中迟熟中粳分别低 9.32%，早熟晚粳分别低 7.55%。迟熟中粳和早熟晚粳表现较为一致的趋势。

2.6 水稻氮素积累与运转特性与氮素利用效率的相互关系

水稻的氮素利用效率与其氮素积累与转移特性有着密切的联系。其中，水稻的氮素利用效率与有效分蘖临界叶龄期、抽穗期和成熟期的氮素积累量存在显著或极显著正相关，相关系数分别达 0.68*、0.93**和 0.97**，而其与拔节期水稻氮素的积累量无显著相关 (r = 0.34)。水稻氮素利用效率与移栽至有效分蘖临界叶龄、拔节至抽穗和抽穗至成熟阶段的氮素积累量呈显著或极显著正相关，相关系数分别为 0.68*、0.98**和 0.97**，与有效分蘖临界叶龄至拔节阶段的氮素累积量呈显著负相关，相关系数为 －0.55*。水稻氮素利用效率与不同生育阶段氮素积

累率的相关性分析表明, 水稻氮素利用效率与移栽至有效分蘖临界叶龄和有效分蘖临界叶龄至拔节阶段的氮素吸收率呈极显著负相关, 相关系数分别达－0.88**、－0.99**, 与拔节至抽穗和抽穗至成熟阶段的氮素吸收率呈极显著正相关, 相关系数分别达0.72**、0.93**。不仅如此, 水稻的氮素利用效率与水稻植株抽穗前氮素的转移量和转移率也呈极显著的正相关, 相关系数分别达 0.97**和 0.88**, 与抽穗前氮对籽粒的贡献率呈极显著的负相关, 相关系数达－0.93**。

表 4　不同氮效率类型水稻氮素转移特性的差异
Table 4　Diversity of characteristics of N translocation in rice types with different N use efficiencies

品种类型 Rice type	生育期 Grouth stage	基因型 Genotype	NT (kg hm^{-2})	NTE (%)	NCR (%)
LMMR	NLE	农垦 57 Nongken 57	53.4412 Bc	52.73 BCb	64.16 Aa
		武农早 Wunongzao	56.5384 Bb	52.38 CDb	62.34 Ab
		郑稻 5 号 Zhengdao 5	53.7124 Bbc	50.78 Dc	59.31 Bc
	NE	9 优 418　9 you 418	67.0246 Aa	55.06 Aa	55.21 De
		武育粳 3 号 Wuyujing 3	64.4635 Aa	54.34 ABa	57.32 Cd
		扬粳 9538 Yangjing9538	65.0336 Aa	53.97 ABCa	55.96 CDe
EMLR	NLE	镇稻 196 Zhendao 196	60.3393 Bc	52.77 CDb	57.74 Bb
		香粳 20-18 Xiangjing 20-18	61.2949 Bc	53.18 BCDb	57.53 Bb
		T1-56	61.1041 Bc	52.47 Db	59.36 Aa
	NE	86 优 8 号　86 you 8	67.9770 Ab	54.08 ABCa	54.31 Cc
		武粳 15 Wujing 15	70.0136 Aab	54.66 Aa	52.75 Dd
		泗优 422 Siyou 422	71.5663 Aa	54.37 ABa	54.38 Cc

标以不同大、小写字母的数值分别具 1%和 5%显著差异。NT: 灌浆期茎叶氮素表观转移量; NTE: 灌浆期茎叶氮素表观转移率; NCR: 灌浆期转移的氮对籽粒的贡献率。

Values followed by a different letter are significantly different at 1% (capital) and 5% (small) probability levels, respectively. NT: Nitrogen translocation amount; NTE: Nitrogen translocation efficiency; NCR: Contribution rate of transferred nitrogen. Abbreviations as in Table 1.

3　讨论

3.1　关于不同氮效率类型水稻氮素积累与转移特性的分析

已有的研究表明[9-12], 不同基因型水稻成熟期的氮素积累量具有很大差异。但各基因型水稻氮素积累在水稻全生育期中动态变化的差异及其与水稻最终氮素利用效率的相互关系尚不十分明了。本研究表明, 有效分蘖临界叶龄期、抽穗期和成熟期, 氮高效类型水稻的氮素积累量均显著大于氮低效类型, 但拔节期没有明显的优势。综合分析氮素阶段积累的特性, 造成这一现象的表面原因在于有效分蘖临界叶龄至拔节阶段, 氮低效基因型的氮素吸收量极显著大于氮高效基因型, 而其根本原因在于该阶段氮低效类型水稻的无效分蘖大量发生[8], 物质生产增加的同时增强了植株对氮素的吸收。虽然无效分蘖衰退时, 作为可移动元素的氮可以进一步运输至其他器官再利用, 但这不仅在时间上具有一定的滞后性, 同时也影响了该阶段有效分蘖的正常生长。本研究还发现, 移栽至有效分蘖临界叶龄、拔节至抽穗和抽穗至成熟阶段, 氮高效基因型的阶段性吸收量均显著大于氮低效基因型。

就水稻氮素的积累与转移特性而言, 有研究认为[13-14], 要提高水稻的氮素利用效率必须提高抽穗前的氮素积累量、抽穗后的干物质积累和氮素运转量。本研究的结果与其较为一致, 但同时又有新的发现。虽然水稻的氮素利用效率与抽穗期的氮素积累量呈极显著正相关, 但与移栽至有效分蘖临界叶龄和有效分蘖临界叶龄至拔节阶段的氮素积累率呈极显著负相关, 与拔节至抽穗阶段的积累率呈极显著正相关。因此, 氮素高效利用水稻类型不仅在抽穗前具有较高的氮素积累, 同时还具有在有效分蘖临界叶龄期前氮素适度积累, 有效分蘖临界叶龄期后, 氮素有效积累强而无效积累弱的特点。虽然水稻的氮素利用效率与抽穗前的氮素转移量和转移率呈极显著正相关, 但与抽穗前氮对籽粒的贡献率呈极显著负相关, 同时与抽穗至成熟阶段的氮素积累量也呈极显著正相关。由此可见, 氮高效类型水

稻与低效类型相比，不仅在抽穗前积累了大量的氮素，以便于生殖生长阶段向籽粒输送[15]，同时在抽穗以后，仍然具有较强的氮素积累能力，积累大量的氮素并输往籽粒，因此其抽穗前氮对籽粒的贡献率要低于氮低效类型。因而本研究认为增强水稻抽穗以后的氮素积累能力对于提高水稻的氮素利用效率同样具有重要的作用。

3.2 关于提高水稻氮素利用效率可能调控途径的思考

不同氮效率类型水稻氮素积累与转移的特性，不仅可以从一个方面解释其氮素吸收与利用差异的原因，同时也为生产上提高水稻的氮素利用效率提供了可以借鉴的调控途径。目前生产上提高水稻氮素利用效率的调控途径主要是适当的氮肥管理措施和品种的遗传改良[16-17]。根据本研究的结果，依据品种氮素积累和转移特性，严格控制基肥和分蘖肥的施用时间和用量[18]，在保证水稻移栽至有效分蘖临界叶龄阶段氮素适度积累的同时减少有效分蘖临界叶龄至拔节阶段氮素的积累。穗肥施用时期的适当提前，在保花促花，提高水稻产量的同时维持水稻生长中后期较高的根系活力，增强植株对氮素的吸收，都是提高水稻氮素利用效率可行的氮肥管理措施。有关水稻氮素利用遗传改良的研究，目前主要集中在氮素利用高效基因型的筛选及其与干物质等性状的配合力方面[19]。事实上，水稻一生中对氮素的吸收利用是一个系统工程，不仅涉及各水稻品种与氮素利用相关基因的差异，同时其生长发育的各项指标均对水稻的氮素利用效率有着重要的影响[20]，上述各项指标构成了决定水稻氮素利用基因型差异的生理生化机制。因此，系统研究该生理生化机制，研究各项机理性指标与水稻氮素利用效率的配合力及协同改良，对于提高生产上水稻的氮素利用效率也具有重要的意义。

4 结论

不同氮效率类型水稻其氮素的积累与转移存在鲜明的差异，是导致各类型水稻氮素利用效率产生差异的重要原因之一。不同氮效率类型的水稻，均具有抽穗前积累了一生中大部分氮素的特点，相对于氮低效类型，氮高效类型水稻在有效分蘖临界叶龄期前氮素适度积累，有效分蘖临界叶龄期后，氮素有效积累高而无效积累低；不仅在抽穗期积累了大量的氮素，具有较高的氮素转移量和转移率，同时，在抽穗以后仍然积累大量的氮素并输往籽粒，表现抽穗前氮对籽粒相对较低的贡献率。

References

[1] Ramasamy S, Berge H F M, Purushothaman S. Yield formation in rice in response to drainage and nitrogen application. *Field Crops Res*, 1997, 51: 65–82

[2] Jing Q, Bouman B A M, Hengsdijk H, Keulen H V, Cao W. Exploring options to combine high yields with high nitrogen use efficiencies in irrigated rice in China. *Eur J Agron*, 2007, 26: 166–177

[3] Jiang F-Y (江福英), Weng B-Q (翁伯琦). NO_3^--N pollution in field and its prevention. *Fujian J Agric Sci* (福建农业科学), 2003, 18(3): 196–200 (in Chinese with English abstract)

[4] Inthapanya P, Sipaseuth, Sihavong P, Sihathep V, Chanphengsay M, Fukai S, Basnayake J. Genotype differences in nutrient uptake and utilization for grain yield production of rainfed lowland rice under fertilised and non-fertilised conditions. *Field Crops Res*, 2000, 65: 57–68

[5] Koutroubas S D, Ntanos D A. Genotypic differences for grain yield and nitrogen utilization in *indica* and *japonica* rice under Mediterranean conditions. *Field Crops Res*, 2003, 83: 251–260

[6] Piao Z-Z (朴钟泽), Han L-Z (韩龙植), Koh H J (高熙宗). Variations of nitrogen use efficiency by rice genotype. *Chin J Rice Sci* (中国水稻科学), 2003, 17 (3): 233–238 (in Chinese with English abstract)

[7] Bao S-D(鲍士旦). Agricultural Chemistry Analysis in Soil (土壤农化分析), 3rd edn. Beijing: China Agriculture Press, 2000. pp 44–49 (in Chinese)

[8] Wei H-Y(魏海燕), Zhang H-C (张洪程), Dai Q-G (戴其根), Huo Z-Y (霍中洋), Xu K (许轲), Hang J (杭杰), Ma Q (马群), Zhang S-F (张胜飞), Zhang Q (张庆), Liu Y-Y (刘艳阳). Characteristics of matter production and accumulation in rice genotypes with different N use efficiency. *Acta Agron Sin* (作物学报), 2007, 33(11): 1802–1809 (in Chinese with English abstract)

[9] Tirol-padre A, Ladhs J K, Singh U, Laureles E, Punzalan G, Akita S. Grain yield performance of rice genotypes at suboptimal levels of soil N as affected by N uptake and utilization efficiency. *Field Crops Res*, 1996, 46: 127–143

[10] Inthapanya P, Sipaseuth, Sihavong P, Sihathep V, Chanphengsay M, Fukai S, Basnayake J. Genotypic performance under fertilized and non-fertilized conditions in rainfed lowland rice. *Field Crops Res*, 2000, 65: 1–14

[11] Shan Y-H (单玉华), Wang H-H (王海候), Long Y-C (龙银成), Wang Y-L(王余龙), Pan X-B (潘学彪). Differences of nitrogen uptake and utilization in rice lines with various sink potentials. *J Yangzhou Univ* (Agric & Life Sci Edn) (扬州大学学报 · 农业与生命科学版), 2004, 25(1): 41–45 (in Chinese with English abstract)

[12] Zhang Y-F (张岳芳), Wang Y-L (王余龙), Zhang C-S (张传胜), Dong G-C (董桂春), Yang L-X (杨连新), Huang J-Y (黄建晔), Chen P-F (陈培锋), Gong K-C (龚克成). Differences of nitrogen absorption and utilization and their influences on grain yield of conventional indica rice cultivars. *Jiangsu J Agric Sci* (江苏农业科学), 2006, 22 (4): 318–324 (in Chinese with English abstract)

[13] Ntanos D A, Koutroubas S D. Dry matter and N accumulation and translocation for indica and japonica rice under Mediterranean conditions. *Field Crops Res*, 2002, 74: 93–101

[14] Jiang L G, Dai T B, Jiang D, Cao W X, Gan X Q, Wei S Q. Charactering physiological N-use efficiency as influenced by nitrogen management in three rice cultivars. *Field Crops Res*, 2004, 88: 239–250

[15] Zhang Y-H (张耀鸿), Zhang Y-L (张亚丽), Huang Q-W (黄启为), Xu C-Y (徐春阳), Shen Q-R (沈其荣). Effect of different nitrogen application rates on grain yield and nitrogen uptake and utilization by different rice cultivars. *Plant Nutr Fert Sci* (植物营养与肥料学报), 2006,12(5): 616–621(in Chinese with English abstract)

[16] Peng S-B (彭少兵), Huang J-L (黄见良). Research strategy in improving fertilizer-nitrogen use efficiency of irrigated rice in China. *Sci Agric Sin* (中国农业科学), 2002, 35(9): 1095–1103 (in Chinese with English abstract)

[17] Ladha J K, Kirk G J D, Bennett J, Peng S, Reddy C K, Reddy P M, Singh U. Opportunities for increased nitrogen-use efficiency from improved lowland rice germplasm. *Field Crops Res*, 1998, 56: 41–71

[18] Wan L-J(万靓军), Zhang H-C(张洪程), Hou Z-Y(霍中洋), Lin Z-C(林忠诚), Dai Q-G(戴其根), Xu K(许轲), Zhang J(张军). Effects of nitrogen application regimes on yield, quality, and nitrogen use efficiency of super japonica hybrid rice. *Acta Agron Sin* (作物学报), 2007, 33(2): 175–182 (in Chinese with English abstract)

[19] Piao Z-Z(朴钟泽), Han L-Z(韩龙植), Koh H J(高熙宗), Zhang J-M(张建明), Lu J-A(陆家安), Li P-D(李培德). Analysis on combining ability of dry weight and nitrogen use-efficiency in rice. *Chin J Rice Sci* (中国水稻科学), 2005, 19(6): 527–532(in Chinese with English abstract)

[20] Jiang L-G (江立庚), Cao W-X (曹卫星). Physiological mechanism and approaches for efficient nitrogen utilization in rice. *Chin J Rice Sci* (中国水稻科学), 2002, 16(3): 261–264 (in Chinese with English abstract)