RECENT DEVELOPMENTS IN YIELD INCREASING THEORY FOCUSING ON NITROGEN USE EFFICIENCY

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ABSTRACT

Increasing the yield potential of rice in response to global population increases and arable land decreases is a crucial research target. The approaches to meeting this goal are new varieties development together with innovative crop managements. Particularly, water scarcity is a challenge for the future in rice-growing regions, and alternate wetting and drying (AWD) rice cultivation and aerobic rice cultivation have been developed to address this issue (Bouman *et al*. 2007). To innovate the rice production system adapted to low fertilizer input is another approach for the future of our resource limited globe. For this purpose, we have been trying to clarify the genetic factor(s) of root N uptake characteristics and root system development. Obara *et al.* (2011) mapped and verified the quantitative trait locus/loci (QTL) for root elongation in response to exogenous NH_4^+ concentration and estimated the candidate gene responsible for that QTL by comparative mapping with genes for NH_4^+ uptake and nitrogen metabolism. Rice breeding program with DNA marker by using genes related to beneficial root trait as well as other traits such as plant architecture and yield components will be carried out by close collaboration with crop physiologist and agronomists in the JIRCAS project entitled “Rice innovation for environmentally sustainable production systems (2011-2015)”.

Kirk *et al.* (2001) simulated the uptake of nitrogen near root surface and estimated the significant uptake of NO_3^- (one third of N uptake) by rice root even under the submerged condition, although rice plant was belived to take up nitrogen mainly as NH_4^+ under submerged soil condition. The production of NO_3^- is attributed to the nitrification of NH_4^+ near root surface where oxygen is transported from atmosphere through aerenchyma. The synergistic effect of NH_4^+ and NO_3^- on N uptake was shown where NO_3^- seems more favorable than NH_4^+ in terms of its uptake and storage/assimilation (Kronzucker *et al.*1999). Duan *et al*. (2006) supported this estimate by using hydroponically grown rice plants. According to their results, there is also a varietal differences in the effect of NO_3^- on biomass production and grain yield when both nitrogen sources are applied. Analysis by Michaelis-Menten kinetics showed that NO_3^- affect Vmax rather than Km of NH_4^+ uptake (Duan et al. 2007). This suggests the beneficial effect of NO_3^- on NH_4^+ transporters. The molecular biological study on the mechanism of this NO_3^- effect was also carried out (Zhao *et al*. 2008).

We examined the response of several rice varieties under NH_4^+, NO_3^-, and partial nitrate nutrition (NH_4^+/ NO_3^-) in solution culture (Senoo *et al.* 2007). Result showed that rice varieties can be grouped by their biomass production; improved varieties have relatively low physiological N use efficiency (PNUE) while some native varieties have higher PNUE, especially under partial nitrogen nutrition.The increase in biomass production was attributable both to the higher N uptake and higher PNUE with NO_3^- nutrition.

Submerged paddy field condition has been believed to show the higher yield potential of lowland rice than upland conditions. However, recent investigations by Kato *et al*. (2009) and Katsura *et al*. (2010) have suggested the possibility that upland condition without severe water stress could be more appropriate to show the potential ability of rice plant. Katsura *et al*. (2010) showed the significantly higher radiation use efficiency (RUE) as well as higher fraction of radiation intercepted under upland conditions compared to submerged ones. Thakur *et al*. (2010) assessed the physiological effects of saturated water management practice comparing with submerged soil conditions and showed higher intercepted radiation during the reproductive stage as well as increase of rooting depth and RUE for saturated water management. These findings suggest the involvement of nitrate uptake for such improved RUE.

The genetic and physiological study of partial nitrogen nutrition in rice plant could contribute to the increase of nitrogen use efficency of rice plant, hence yield increase under lower nitrogen application environment would be feasible if the aerobic or at least non-severe reductive soil condition without water stress could be achieved by proper water saving management of paddy field.

KEYWORDS

Nitrogen, Root system, Aerobic soil, AWD, Yield potential, Radiation use effciency

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Recent developments in yield increasing theory focusing on Nitrogen Use Efficiency

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JIRCAS

Background and Objectives

- To solve the problems of rice cultivation in developing countries
- Innovation of rice production through research collaboration in breeding and crop management with a new concept

Strategy

- To meet a pressing demand from developing countries such as in Africa
  - ⇨ Use conventional techniques well adapted and updated
- Long –term measures for future demand
  - ⇨ Innovation based on technology breakthrough (This paper deals with)
- Increase of nitrogen use efficiency (NUE) is one of the keys to establish a new system

Points of talk

1. Introduction of Rice Innovation Project
2. Strategy to improve Nitrogen Use Efficiency
3. A breakthrough concept - Nitrate hypothesis

Rice innovation Project (2011-2015)

Rice innovation for environmentally sustainable production systems

1.Resistance to blast disease

- Durable protection system
- Genetic improvement of resistance under a blast research network

2. High productive rice under limited nitrogen fertilizers

- Increasing spikelet No. per panicle with high grain filling
- High dry matter production
- Different root systems
- Genetic improvement for **nitrogen use efficiency**

3. Increasing the adaptability for environmental stresses

- P, Zn deficiency
- Fe toxicity
- Ozone

- Survey and the selection of DNA markers for tolerant gene(s), and development of breeding materials

Way of improving NUE

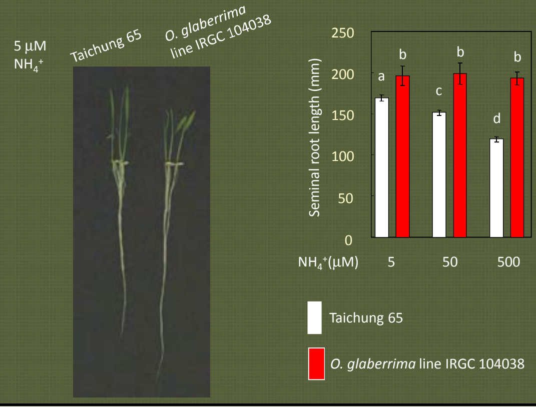
- To improve Agronomic N use efficiency (ANUE)
  1. Breeding high yield variety
  2. Proper adjustment of fertilizer application by plant and soil diagnosis
  3. Breeding of root traits which leads to a larger rhizosphere volume
- To improve Physiological N use efficiency (PNUE)
  1. Discovering the phenomena showing high PNUE and elucidate the physiological mechanism and genetic bases in it

Genetic improvement for nitrogen use efficiency- relating to the root length

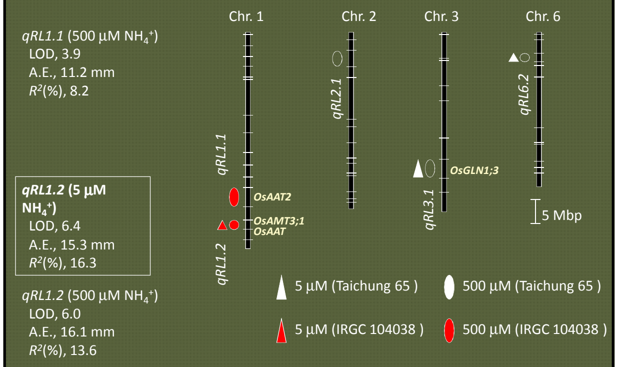
- QTLs for root elongation in response to exogenous NH_4^+ concentration was mapped and verified.
- The candidate gene responsible for the QTL was estimated by comparative mapping with genes for NH_4^+ uptake and nitrogen metabolism.

Obara *et al.* (2011)

Identification of novel QTL for root length traits



Identification of novel QTL for root length traits



Strategy to improve NUE from crop management aspects

- Nutritional diagnosis for nitrogen
- Site-specific management
- Aerobic soil management with little water stress

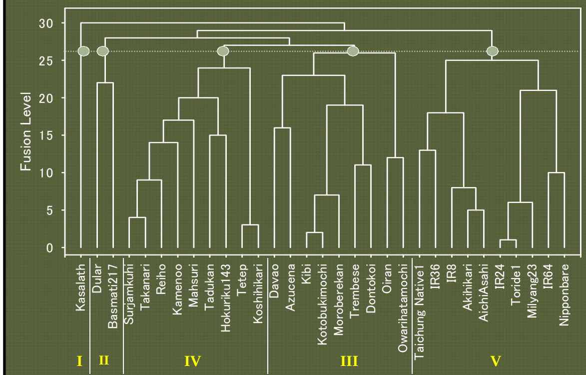
Different response of variety to N concentration in nutrient solution

- 31 rice varieties from Indica, Japonica and local, improved were water cultured by using various concentration of $(NH_4^+ + NO_3^-)$ mixture from 1mg to 80 mgN L^{-1}
- Relative dry weight (RDW) was analyzed by cluster analysis

RDW(%)=(DM of treatment with N / DM of treatment without N) ×100

Namai *et al.* (2009)

Cluster analysis based on dry matter response to N



Namai *et al.* (2009)

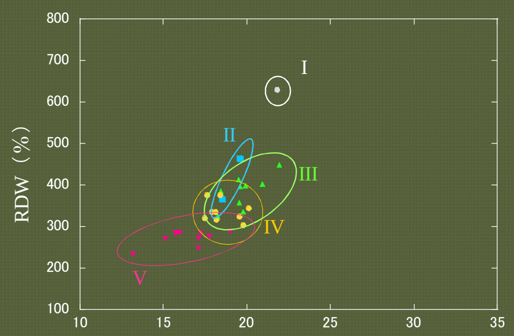
Classified variety groups and their types

	Indica-type		Japonica-type	
	landrace	improved	landrace	improved
I	Kasalath			
II			Basmati217 Dular	
III			Azucena Davao Kibi Moroberekan Oiran Trembese	Dontokoi Kotobukimochi Owarihatamochi
IV	Surjamkuhi Tadukan Tetep	Hokuriku143 Mahsuri Takanari	Kamenoo	Koshihikari Reiho
V		IR8 IR64 IR24 IR36 Taichung Native1 Milyang23		Aichiasahi Akihikari Nipponbare Toride1

Namai *et al.* (2009)

Based on the RDW response, rice varieties could be grouped

Performance of each variety group



Improved varieties have relatively low RDW and PNUE

Effect of N sources on biomass production

Methods

- 30 rice cultivars were water-cultured with NH_4^+, NO_3^- and NH_4^++ NO_3^- mixture
- Relative dry weight (RDW) and PNUE was measured

Senoo *et al.*(2007)

Compare the growth with different N sources

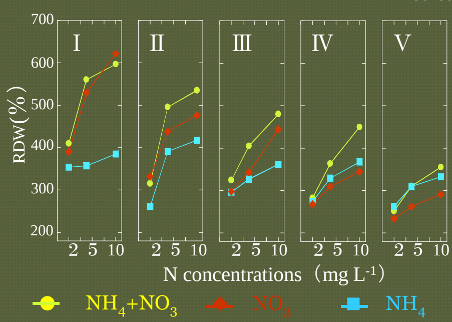
NO_3 $NH_4 + NO_3$ NH_4

N concentrations were 0, 2, 5 and 10 mgL^{-1}

Senoo *et al.*(2007)

Effect of different N sources on biomass production

Senoo *et al.*(2007)



Effect on Relative DW among variety groups are (NH4+NO3) > NO3 > NH4

Effect of N sources : NO_3^- / NH_4^+ (%)

Group	Nup			PNUE			RDW		
	Ave	n	SE	Ave	n	SE	Ave	n	SE
I	129	1		119	1		140	1	
II	84	2	11	103	2	1	90	2	9
III	120	8	13	110	8	5	120	8	12
IV	79	9	5	108	9	2	89	9	4
V	78	10	4	112	10	4	92	10	5
All	92	30	6	110	30	2	100	30	5

Single NO_3^- nutrition increased PNUE significantly but with less N uptake in some variety groups

Effect of N sources : (NH_4^+ + NO_3^-)/ NH_4^+ (%)

Group	Nup			PNUE			RDW		
	Ave	n	SE	Ave	n	SE	Ave	n	SE
Ⅰ	125	1		106	1		125	1	
Ⅱ	119	2	2	101	2	4	115	2	2
Ⅲ	151	8	12	106	8	3	138	8	8
Ⅳ	129	9	8	108	9	2	128	9	7
Ⅴ	117	10	6	105	10	2	116	10	5
All	**126**	30	**4**	**106**	30	**1**	**131**	30	**5**

Partial N nutrition increased N uptake, PNUE and biomass production significantly

Some supporting reports

Effect of NO_3^- uptake on NH_4^+ uptake

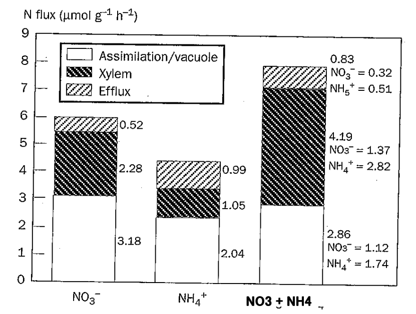
- Co-provision of NH_4^+ and NO_3^- (Partial N nutrition) increase the total N uptake

Kronzucker et al.(1999), Kirk et al. (2001)

- Partial N nutrition enhance the uptake of NH_4^+

Duan et al (2006,2007), Zhao et al.(2008)

Synergistic effect of Partial N nutrition



Carbon and Nitrogen Dynamics in Flooded Soils, Kirk and Kronzucker (2000)

Effect of NO_3^- addition on NH_4^+ uptake

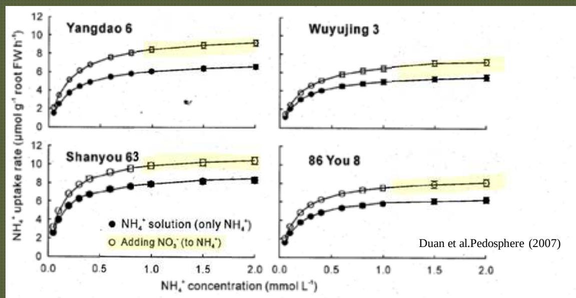


Fig. 3 Rates of NH_4^+ uptake by different rice cultivars as a function of NH_4^+ concentration with added NO_3^- at the seedling stage. The error bar represents SE of means of three replicates.

Michaelis-Menten's Analysis : Km 1 -9% increase, Vmax 25 -30% increase

Proposed NO_3^- effects on the growth of rice plant (1)

- Positive correlation between Nitrate reductase activities (NRA) and biomass production

Barlaan and Ichii. Breeding Sci. (1996)

- Nitrate could be stored in vacuole of shoot tissue and estimated to move to leaf tissue when NO_3^- was depleted

Fan *et al.* J.Exp.Bot. 58 (2007)

Proposed NO_3^- effects on the growth of rice plant (2)

- Field experiment with NO_3^- application suggested the delayed biomass increase compared to NH_4 application in vegetative stage

Yamamuro Bull.Hokuriku Nat.Agr.Exp.Stn(1975)

- Hybrid rice with higher NUE contains more NO_3^- than conventional cultivar between late tillering and heading stage

Yang et al. Int.Rice Res. Notes (1999)

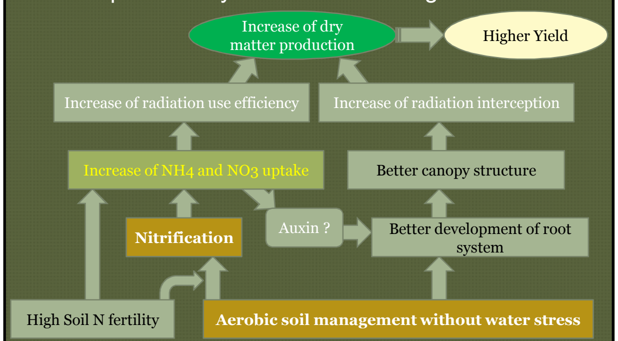
NO_3^- sources in soil and its uptake

- There are three possible NO_3^- sources in paddy soil
  1) surface oxidized layer and irrigated water
  2) rhizosphere
  3) surface soil and bulk soil (if aerated)

Rice productivity under aerobic soil management

- Upland condition without severe water stress could be more appropriate to show the potential productivity of rice plant.
  Kato *et al*. Field Crops Res. (2009)
  Katsura *et al*. Field Crops Res. (2010)
- Significantly higher radiation use efficiency (RUE) as well as higher fraction of radiation intercepted under aerocic conditions compared to submerged ones.
  Katsura *et al*. Field Crops Res.(2010)
  Thahur et al. Expl.Agric.(2010)

Hypothetical scheme for a possible high yield potential by aerobic soil management



Future research to be addressed

1. Seek for the optimum conditions under aerobic soil culture for the increased N uptake

   Aerobic condition without water stress is worthy to be explored

2. Clarify the physiological mechanism and genetic bases for the increased PNUE under NO_3^- uptake

   Is there any positive effect of NO_3^- uptake on photosynthesis ?

Goal: Genetic improvement of NUE together with an establishment of a suitable soil management

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Thank you for your attention!

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