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Effects of water management on nitrogen fertilizer uptake and recovery efficiency in rice

(Kesan pengurusan air pada pengambilan dan kecekapan perolehan semula baja nitrogen oleh pokok padi)

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Key words: water management, nitrogen fertilizer, nitrogen uptake, nitrogen recovery efficiency, rice

Abstract

A planthouse experiment was carried out to determine the uptake and recovery efficiency of nitrogen fertilizer applied to rice varieties, MR 84 and Siam, grown under flooded, non-flooded (NF)-saturated and NF-field capacity water management conditions. The total nitrogen uptake and nitrogen fertilizer uptake of rice were higher under flooded and NF-saturated than under NF-field capacity condition irrespective of rice varieties. On average, the recovery efficiency of applied nitrogen fertilizer was 47.7, 43.2 and 30.4% under flooded, NF-saturated and NF-field capacity conditions, respectively. Recovery efficiency of applied nitrogen fertilizer was higher for MR 84 than Siam regardless of water management treatments.

Recovery efficiency of nitrogen fertilizer from soil was 26.1, 26.9 and 18.5% for flooded, NF-saturated and NF-field capacity conditions, respectively. On the contrary, under NF-field capacity condition, the amount of nitrogen fertilizer losses from the plant-soil system was the highest (51.1%), followed by NF-saturated condition (29.9%) and flooded condition (26.2%).

Introduction

Nitrogen (N) fertilizer is a major input for irrigated rice, but its recovery efficiency is relatively low. De Datta (1978) reported that the recovery efficiency of N for wetland rice is between 30% and 40% and in some cases even less. Even with good agronomic practices, similar low recovery in the tropics is observed (Prasad and De Datta 1979). However, the average recovery efficiency of N is about 30% for irrigated rice in Asia (Dobermann and Fairhurst 2000). The magnitude and nature of N losses depends on the timing, rate and method of application, source of N fertilizer, soil chemical and physical properties, climatic conditions and crop status. The low uptake and recovery efficiency of N from wetland rice is mainly due to chemical and biological conditions which induce a peculiar transformation of N involving the operation of several losses mechanisms such as nitrification-denitrification, ammonia volatilization, leaching and runoff simultaneously (Ponnamperuma 1977; De Datta and Buresh 1989). In general, ammonia volatilization is the major pathway of N loss in irrigated rice (Zhu 1997).

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Nitrogen uptake by rice plant is influenced by water management. Yamamuro (1983) reported that flooding increases N uptake in soils with good internal drainage but decreases uptake in poorly drained soil. Nitrogen uptake at booting stage is 30−40% less for flush-irrigated rice as compared with normal flooded rice (Beyrouty et al. 1994).

Reduced N uptake from flush irrigation is postulated to be due to combination of a smaller root system, less dry matter yield as N uptake by rice is parallel to dry matter production (Sims and Place 1968), enhances N losses through denitrification (Patrick and Mahapatra 1968; Wells and Shockley 1978) and leaching as a result of alternate wetting and drying (George et al. 1992).

The experiment was conducted to determine the uptake and recovery efficiency of N fertilizer applied to rice grown under different water management practices.

Materials and methods

A planthouse experiment was conducted at MARDI Station Seberang Perai using sandy clay loam of the Sogomana soil series. The physico-chemical properties of the Sogomana soil series are given in *Table 1.* Two rice varieties, namely MR 84 (modern and N responsive variety) and Siam (traditional and less N responsive variety) were grown in polyvinyl chloride (PVC) cylinders, 20 cm diameter by 50 cm high, each filled with 15 kg air-dry soil. Five seeds of each variety were sown in each pot. This planting density is equivalent to the seeding rate of 40 kg dry seeds per hectare.

Table 1. Physico-chemical properties of Sogomana soil series

Particle size distribution	
Sand (%)	51.5
Silt (%)	12
Clay (%)	36.5
Textural class: Sandy clay loam	
Chemical properties	
pH (1: 2.5 in distilled water)	4.49
Cation exchange (capacity $cmol_c/kg$)	7
Organic C (%)	0.52
Total N (%)	0.13
Available P (mg/kg)	10.38
Exchangeable K ($cmol_c/kg$)	0.21
Exchangeable Mg ($cmol_c/kg$)	0.53
Exchangeable Ca ($cmol_c/kg$)	3.59
Available Cu (mg/kg)	0.14
Available Mn (mg/kg)	3.38
Available Fe (mg/kg)	43.27
Available Zn (mg/kg)	1.01

Each variety was subjected to three different water management treatments: i) Flooded: application of 5 cm standing water from 7 days after seeding (DAS) to about 10 days before maturity, ii) Non-flooded (NF)-saturated: application of water to continuously soak the soil throughout the crop growth period, and iii) Non-flooded (NF)-field capacity: periodic irrigation to maintain the soil at about field capacity from seeding to maturity. Irrigation was done when the water potential fell between –0.03 and –0.05 MPa, as measured with a tensiometer installed at 15 cm soil depth. The experiment was set up as a randomized complete block design with four replications.

Nitrogen in the form of ^{15}N-labeled urea (2.52 % atom excess) was applied at the rate of 100 kg N/ha. Nitrogen was applied in three splits of 40, 30 and 30% of the total N at 21 DAS, 45 DAS and panicle initiation (PI) stage, respectively. Phosphorus in the form of triple super phosphate (TSP) and potassium in the form of muriate of potash (MOP) were applied at the rate 50 kg P_2O_5/ha and 50 kg K_2O/ha, respectively, at 21 DAS. All fertilizers were applied in the solution form to ensure even distribution since small amount was applied per pot.

The rice plants were harvested by cutting about 2 cm above the soil surface at the maturity stage. The plants were separated into grain, straw and root. All the plant parts were washed, oven dried at 70 °C for 72 h and finally weighed. The dried straw, grain and root samples were ground separately to pass 1-mm sieve and preserved in plastic containers for total N and ^{15}N analyses.

Total nitrogen and ^{15}N analysis of plant tissue and soil

The ground straw, grain and root samples were analysed for total N by digesting with H_2SO_4 and followed by steam distillation method (Bremner and Mulvaney 1982). Subsequently, the ^{15}N content of the straw, grain and root samples was analysed using emission spectrometry (Hauck 1982).

For each treatment, three soil cores from its entire depth were sampled after harvest, air dried and mixed to obtain composite samples. These soil samples were ground to pass through 2-mm sieve and analysed for total N (Bremner and Mulvaney 1982) and ^{15}N (Hauck 1982).

The N derived from fertilizer (NdfF) was calculated as:

$$\text{NdfF (\%)} = (\text{AE}_{\text{plant or soil}}/\text{AE}_{\text{fertilizer}}) \times 100$$

Atom excess (AE) in plant, soil and fertilizer as obtained from ^{15}N analysis.

Nitrogen fertilizer uptake and recovery

The amount of ^{15}N recovered from the soil was calculated by multiplying %NdfF with total N in the soil. The N fertilizer uptake and recovery of added N by the rice plant were calculated as follows:

$$\text{Nitrogen fertilizer uptake in straw} = \frac{\text{\%NdfF in straw x total straw N uptake}}{100}$$

$$\text{Nitrogen fertilizer uptake in grain} = \frac{\text{\%NdfF in grain x total grain N uptake}}{100}$$

$$\text{Nitrogen fertilizer uptake in root} = \frac{\text{\%NdfF in root x total root N uptake}}{100}$$

$$\begin{aligned}&\text{Plant uptake of N fertilizer}\\ &= \text{N fertilizer uptake in straw + N fertilizer uptake in grain +}\\ &\quad\ \text{N fertilizer uptake in root}\end{aligned}$$

$$\begin{array}{l}\text{Recovery (\%) of N}\\ \text{fertilizer by rice plant}\\ \text{or soil}\end{array} = \frac{\text{N fertilizer uptake by the plant or soil}}{\text{N fertilizer applied}} \times 100$$

Results and discussion

Plant total nitrogen uptake

The interaction effect between water management and rice varieties was not significant in bringing about the differences in the total N uptake by all parts of MR 84 and Siam at maturity *(Table 2)*. The N uptake by straw, grain and root was significantly higher under flooded and NF-saturated than NF-field capacity condition regardless of rice varieties. The grain and root N uptake under NF-field capacity was about half of that under flooded and NF-saturated conditions. Sims and Place (1968) attributed the low N uptake in straw, grain and root of rice subjected to NF-field capacity condition to lower mass of dry straw, grain and root, since N uptake by rice has been reported to be parallel with dry matter production.

A lower N uptake under NF-field capacity condition could also be the result of low N availability as observed by Beyrouty et al. (1994) due to N losses from denitrification as well as gaseous losses and leaching (George et al. 1992). The condition of wetting and drying of the soil as imposed by the treatment favoured such kind of N losses. The differences of N uptake in straw, grain and root between flooded and NF-saturated conditions were not significant.

The differences in N uptake for both the straw and grain between MR 84 and Siam were also not significant. However, root N uptake was significantly higher for Siam than MR 84 due to higher root biomass of Siam (11.98 g/pot) than MR 84 (8.70 g/pot).

^{15}N-labeled fertilizer uptake by the rice plant

The results of the study using ^{15}N-labeled fertilizer indicated that water management effect gave similar trend of N uptake in all the parts of rice plant as discovered earlier for the plant total N uptake *(Table 2)*. The results of N uptake from fertilizer in straw, grain and root revealed that more than 80% of N in the plant is derived from the mineralization of soil organic N. Khanif (1988) and Shah (1994) also reported that substantial amount of N in the rice plant is derived from soil N. Native soil N is taken up by the rice plants during the entire growing season and it was the main N source at the later growing stage of the crop (Cao et al. 1984). The substantial amount of soil N in the plant indicated that rice plant depended more on soil N even when N fertilizer was applied.

Besides water management, rice variety had significant N fertilizer uptake by the straw, grain and root. The modern rice variety MR 84 was more responsive to N fertilizer. It promoted a higher N fertilizer uptake in the straw and grain when compared to Siam, a traditional variety. Considering the non-significant difference in total N uptake between MR 84 and Siam for both the straw and grain *(Table 2)*, this result proved that Siam adsorbed higher N from soil rather than from N fertilizer. This was possibly brought about by the differences in root mass. Siam had a higher amount of root (11.98 g/pot) than MR 84 (8.70 g/pot) at maturity stage irrespective of water management treatments. Averaged across variety, a higher N uptake from fertilizer was observed in grain (63.8 mg/pot) than in straw (50.7 mg/pot). A higher N uptake in the root was also observed for Siam than MR 84 which could be due to a higher root biomass of Siam.

Nitrogen fertilizer recovery efficiency of the rice plant

The interaction effect between water management and rice variety on recovery efficiency of N fertilizer was not significant as shown in *Table 3*. The N fertilizer recovery efficiency was significantly affected by water management as well as rice variety. Averaged across variety, the differences in N fertilizer recovery efficiency of rice grown under flooded and NF-saturated conditions was not significant, about 47.7% and 43.2% respectively. In contrast, N fertilizer recovery efficiency under NF-field capacity condition (30.4%) was significantly lower than flooded and NF-saturated conditions.

Since Siam is a traditional variety and less responsive to N fertilizer application, N

Table 2. Total nitrogen and ^{15}N-labeled fertilizer uptake (mg/pot) in straw, grain and root of MR 84 and Siam at maturity as influenced by water management

Water management	Straw			Grain			Root		
	MR 84	Siam	Mean	MR 84	Siam	Mean	MR 84	Siam	Mean
Total nitrogen uptake									
Flooded	363.0	345.0	354.0a	575.5	584.0	579.8a	106.9	138.7	122.8a
NF-saturated	415.6	354.7	385.2a	502.0	560.9	531.5a	104.9	144.0	124.4a
NF-field capacity	288.0	227.8	257.9b	285.3	215.4	250.4b	49.9	68.5	59.2b
Mean	355.5A	309.2A	332.4	454.3A	453.4A	453.9	87.2B	117.1A	102.1
CV (%)			19.5			9.1			17.0
^{15}N-labeled fertilizer uptake									
Flooded	60.3	47.6	54.0a	90.6	71.4	81.0a	14.3	15.1	14.7a
NF-saturated	61.9	48.7	55.3a	76.2	58.1	67.2b	11.5	14.7	13.1a
NF-field capacity	44.3	41.0	42.7b	46.2	40.2	43.2c	7.5	11.9	9.7b
Mean	55.5A	45.8B	50.7	71.0A	56.6B	63.8	11.1B	13.9A	12.5
CV (%)			22.1			9.3			20.9

Means in a column followed by a common small letter and in a row of each parameter followed by a common capital letter are not significantly different at 5% level by DMRT

Table 3. Effects of water management on ^{15}N-labeled fertilizer recovery efficiency of MR 84 and Siam at maturity

Water management	N fertilizer recovery (%)		
	MR 84	Siam	Mean
Flooded	52.6	42.8	47.7a
NF-saturated	47.6	38.7	43.2a
NF-field capacity	31.2	29.7	30.4b
Mean	43.8A	37.0B	40.4
CV (%)			10.6

Means in a column followed by a common small letter and in a row followed by a common capital letter are not significantly different at 5% level by DMRT

Table 4. ^{15}N-labeled fertilizer recovery from soil at maturity under different water management treatments

Water management	N fertilizer recovered from soil					
	MR 84	Siam	Mean	MR 84	Siam	Mean
	(mg/pot)			(%)		
Flooded	84.3	79.8	82.1a	26.9	25.4	26.1a
NF-saturated	88.8	80.3	84.5a	28.3	25.6	26.9a
NF-field capacity	66.4	49.5	58.0b	21.2	15.8	18.5b
Mean	79.8A	69.9A	74.9	25.4A	22.3A	23.8
CV (%)			18.3			18.3

Means in a column followed by a common small letter and in a row followed by a common capital letter are not significantly different at 5% level by DMRT

recovery efficiency for Siam was observed to be lower (37%) than MR 84 (43.8%) irrespective of water management treatments. This low N fertilizer recovery efficiency of Siam was probably due to its inability to take up N losses through denitrification and leaching (Wells and Shockley 1978; George et al. 1992).

Nitrogen fertilizer recovery from soil

The interaction effect between rice variety and water management had no significant influence on the N fertilizer recovery from soil as shown in *Table 4*. Nitrogen fertilizer recovery was significantly affected by water management but not rice variety. The N fertilizer recovered from the soil under flooded and NF-saturated conditions was significantly higher than NF-field capacity condition.

However, the differences in N recovered from soil were not significantly different between flooded and NF-saturated condition. The amount of N recovered from soil was 26.1, 26.9 and 18.5%, for flooded, NF-saturated and NF-field capacity conditions, respectively *(Table 4)*. A recovery of 15% and 20% of applied N from soil has been reported by Shah (1994) and Wilson et al. (1989), respectively.

Nitrogen fertilizer losses

Nitrogen fertilizer losses was calculated by the difference between N fertilizer (urea-^{15}N) added and N fertilizer (urea-^{15}N) recovered in the plant-soil system. The interaction effect between water management and rice variety on N fertilizer losses was not significant *(Table 5)*. Nitrogen fertilizer losses were significantly higher under NF-field capacity than flooded and NF-saturated conditions. On average, the amounts of N fertilizer loss were 26.2, 29.9 and 51.1% under flooded, NF-saturated and NF-field

Table 5. Effects of water management on ^{15}N-labeled fertilizer losses at maturity

Water management	N fertilizer losses (%)		
	MR 84	Siam	Mean
Flooded	20.6	31.9	26.2b
NF-saturated	24.1	35.7	29.9b
NF-field capacity	47.7	54.6	51.1a
Mean	30.8B	40.7A	35.8
CV (%)			19.4

Means in a column followed by a common small letter and in a row followed by a common capital letter are not significantly different at 5% level by DMRT

capacity condition, respectively. The results also showed that N fertilizer losses under the traditional less responsive rice variety, Siam (40.7%) were significantly higher than the modern N responsive variety, MR 84 (30.8%).

The higher losses of applied N under NF-field capacity condition were probably due to denitrification, leaching and gaseous losses as a result of wetting and drying of the soil since the actual N losses were not measured in this study. The applied N fertilizer applied was not readily taken up by the less N responsive rice variety (Siam) resulted in a significantly higher N losses through various mechanisms (Wells and Shockley 1978; George et al. 1992; Peoples et al. 1995) than the N responsive variety (MR 84).

Conclusion

The uptake, recovery efficiency and eventually losses of N fertilizer applied to rice were strongly influenced by water management. A significantly higher N fertilizer uptake and recovery efficiency but lower N fertilizer losses were observed under flooded and NF-saturated than NF-field capacity condition. In the case of varietal effect, the N responsive variety, MR 84, promoted significantly higher N fertilizer uptake, recovery efficiency but lower N losses as compared to the traditional variety, Siam. The results seem to suggest that the modern and N responsive variety such as MR 84 has a better potential to be grown under minimum water of NF-saturated condition. It will not cause significant negative effects on N uptake and N fertilizer recovery efficiency when compared to rice grown under flooded condition. Unlike NF-saturated condition, N fertilizer uptake and recovery efficiency were significantly lower and N losses were significantly higher when rice regardless of variety was subjected to NF-field capacity condition.

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Abstrak

Kajian di rumah tanaman telah dilakukan untuk menentukan pengambilan dan kecekapan perolehan semula baja nitrogen oleh pokok padi varieti MR 84 dan Siam yang ditanam dalam keadaan pengurusan air yang berbeza iaitu pembanjiran, tanpa pembanjiran (TB)-tepu dan TB-keupayaan ladang. Pengambilan keseluruhan nitrogen dan baja nitrogen oleh pokok padi adalah lebih tinggi dalam keadaan pembanjiran dan TB-tepu berbanding dengan TB-keupayaan ladang tanpa mengira varieti padi. Purata kecekapan perolehan semula baja nitrogen oleh pokok padi adalah sebanyak 47.7, 43.2 dan 30.4%, masing-masing dalam keadaan pembanjiran, TB-tepu dan TB-keupayaan ladang.

Kecekapan perolehan semula baja nitrogen adalah lebih tinggi bagi varieti MR 84 berbanding dengan Siam tidak kira perlakuan pengurusan air. Kecekapan perolehan semula baja nitrogen dari tanah pula adalah sebanyak 26.1, 26.9 dan 18.5%, masing-masing dalam keadaan pembanjiran, TB-tepu dan TB-keupayaan ladang. Sebaliknya dalam keadaan TB-keupayaan ladang, kadar kehilangan baja nitrogen dari sistem pokok-tanah adalah paling tinggi (51.1%), diikuti oleh keadaan TB-tepu (29.9%) dan keadaan pembanjiran (26.2%).

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