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Improvement of Nitrogen Efficiency by N Application at Early Tillering Stage in Direct-Seeded Rice

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ABSTRACT: This study was conducted to establish the elaborate nitrogen fertilization method to enhance N use efficiency in direct-seeded rice on flooded paddy. The nitrogen uptake by rice plants was insignificant until 25 days after seeding, and increased gradually thereafter. During this early growth stage, rice plants absorbed only the 4% of basal applied N, while the 45% of N fertilizer remained in the paddy soil. The absorption of basal N by rice plants was almost completed at 46 days after application. Nitrogen top-dressed at 5-leaf stage was well matched to crop nutrient demand, so it could be absorbed so actively in 8 days after application. As a result, we could cut down the amount of N fertilizer to 36% of the basal N level without significant difference in yield. Plant recoveries of fertilizer ^{15}N applied with different application timings were 7.8% for basal, 9.4% for 5-leaf stage, 17.1% for tillering stage, and 23.4% for panicle initiation stage, respectively. When urea was applied with nitrogen fertilization practice based on basal incorporation (BN), plant recovery of ^{15}N at harvest was 31.0%, which was originated from 13.7% for grain, and 21.3% of the fertilizer ^{15}N remained in the soil, and the rest could be uncounted. Plant recovery of fertilizer ^{15}N applied with nitrogen fertilization practice based on topdressing at 5-leaf stage (TN), where N rate was reduced by 18% compared with BN, was 35.1% (grain 15.6%), and 19.9% of the fertilizer ^{15}N remained in the soil, and the rest could be uncounted. TN showed a higher ^{15}N recovery than BN because it was to apply N fertilizer at a time to well meet the demand of rice plant direct-seeded on flooded paddy. We concluded that TN would be the nitrogen fertilization method to enhance N use efficiency in direct-seeded rice on flooded paddy.

Keywords: rice, nitrogen fertilization method, N use efficiency, N uptake, plant recovery of ^{15}N

In the intensive agricultural systems, nitrogen is the most essential element in determining the yield potential of crops, and fertilizer N is one of the major inputs to agricultural systems. The understanding of relationships among growth, yield and N utilization in rice plants is pivotal for the development of rice varieties with greater yield potential. Nitrogen fertilizer use efficiency was relatively low in irrigated rice because of rapid N losses from volatilization and denitrification in the soil-flood water system (Vlek & Byrnes, 1986; De Datta & Buresh, 1989; Freney *et al.*, 1990). Improving the congruence between crop N short-term uptake requirements during the growing season and the available N supply from indigenous and applied N can result in greater N use efficiency (Peng *et al.*, 1996).

Direct-seeded rice culture on flooded paddy has more advantages in saving the labor demands for rice production than transplanting. Unlike transplanting, however, direct-seeded rice seedlings may not require the large amount of N fertilizer until the 5-leaf stage when it takes about a month for the rice to grow. During this period, basal N fertilizer can be lost easily via N transformation process. Thus, nitrogen use efficiency of direct-seeded rice culture on flooded paddy is less than that of transplanting in conventional N management system in temperate countries like Japan (Escabarte *et al.*, 1999).

Plant recovery of fertilizer N differs with different application time. In transplanting, the absorption of basal N by rice plants was almost completed at the maximum tiller number stage, and the plant recovery varied from 20 to 40% in most cases (Shoji & Mae, 1984). The plant absorption of N top-dressed at 14 days after transplanting was largely finished by the 40th day after the topdressing and plant recovery was about 15% (Tanaka, 1983). The absorption of N top-dressed at panicle formation stage was finished by the 7th day after the topdressing and the recovery was ranged from 44 to 68% (Ando *et al.*, 1985).

Topdressing of N can change drastically N absorption by rice plants, and it can be one of useful fertilization practices in case of N loss favorable cultivation systems. Since Reddy & Patrick (1976) found that split application of fertilizer N resulted in higher recovery of N in the grain and straw, research has demonstrated the importance of split applications for reducing losses of fertilizer N. In direct-seeded rice on flooded paddy, however, only limited information is available concerning the seasonal uptake of N and the differences in N efficiency for fertilizer applications made at different stages of plant development. Therefore, this study was designed to investigate the seasonal uptake of fertilizer

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N applied with different split practices, and the objective of this study was to establish the nitrogen fertilization method to enhance N use efficiency in direct-seeded rice on flooded paddy.

MATERIALS AND METHODS

The field experiment was conducted on a sandy loam soil (a mixed, nonacid, mesic family of Fluvaquentic Eutrudepts) at the Experimental Farm of Seoul National University, Suwon, Korea in 2000. The soil in the plow layer contained 27 g kg^{-1} organic matter, 1.2 g kg^{-1} total N, and had a pH of 5.7, 11.2 cmol (+) kg^{-1} of CEC prior to flooding. The presoaked seed of rice cultivar Hwasungbyeo was direct-seeded with a 30-cm row spacing into flooded paddy soil at a rate of 56 kg seed/ha to establish the plant density of 32 plant per 1-m row.

All the plots were arranged in a randomized complete block design with three replications. Main plots consisted of the two nitrogen fertilization methods and each of them consisted of three N timing treatments applied in a random. These micro-plots were formed with acryl squares having heights of 40 cm and enclosed areas of 0.81 m^2. These were driven into the soil to a depth of 18 cm to prevent diffusion of labeled materials away from the area of treatment through soil or flood water. ^{15}N-labeled urea (5 atom % ^{15}N excess) was applied just before seeding inside the micro-plot and incorporated by hand into the mud at 15 cm depth. Unlabeled urea was applied to the main plots outside the micro-plots with the different N split applications. All the treatments were summarized in table 1. P_2O_5 and 70 % of K_2O were blanketed at the rates of 70 kg and 56 kg ha^{-1}, respectively, and incorporated into soil during puddling. The other 30% of K_2O was top-dressed at the rate of 24 kg ha^{-1} at panicle initiation stage.

Soil samples taken at a depth of 15cm were all collected from two sites inside the micro-plots using core soil sampler. Plant samples were all collected inside the micro-plots with three replications. Plants were separated into leaf (leaf blade) and culms (leaf sheath + stem) before heading, and thereafter, they were separated into three parts by adding panicle. At harvest, plants were divided into five parts by separating root. All the plants were oven-dried at 80°C to a constant weight, weighed, and ground, and subsamples were taken for N analysis. Nitrogen isotope-ratio analyses were determined on all plant and soil samples with a Isoprime-EA mass spectrometer. Nitrogen derived from fertilizer (NDFF) was calculated based on the following.

$$NDFF(\%) = \frac{(\text{plant or soil}^{15}\text{Natom\%} - 0.3708)}{(\text{fertilizer}^{15}\text{Natom\%} - 0.3663)} \times 100$$

Results were analyzed statistically using SAS software (SAS Inst., Cary, NC). Treatments effects was compared by F-test and Duncans Multiple Range Test Method with Least Significance Difference (LSD) at $\alpha \le 0.05$.

RESULTS AND DISCUSSION

Fertilizer N in paddy soil

Total nitrogen contents of paddy soil were not significantly fluctuated in all treatments though the growing period. Nitrogens derived from fertilizer (NDFF) were different with N application timings. For basal N, NDFF reached to about 2% immediately after application, declined to below 1% 45d after application and remained constantly thereafter. NDFF for topdressing at 5-leaf stage remained below 1% after application. NDFFs for topdressing at tillering stage and at panicle initiation stage showed the same patterns as for topdressing at 5-leaf stage.

Seasonal patterns of remaining of fertilizer N in soil were significantly different with different application timings. Fertilizer N applied with basal incorporation remained about 50% within 20 days after application, and it could be stable at 28% from 46 days after application to harvest in paddy soil. Fertilizer N top-dressed at 5-leaf stage was decreased to stable level, so duration of remaining in soil was 18 to 21 days. Fertilizer N top-dressed at tillering stage was decreased rapidly to stable level, so duration of remaining in soil was 6 to 8 days. It was the same for fertilizer N top-dressed at panicle initiation stage (Fig. 1).

Table 1. Amount and split application rate of ^{15}N-labeled and unlabeled urea applied on direct-seeded rice on flooded paddy soil.

Treatments	Total N (N kg/ ha)	Basal N	Topdressing at 5LS	Topdressing at TS	Topdressing at PIS
B N (b)	110	55(^{15}N)	0	33†	22†
B N (t)	110	55†	0	33(^{15}N)	22†
B N (p)	110	55†	0	33†	22(^{15}N)
T N (f)	90	0	35(^{15}N)	33†	22†
T N (t)	90	0	35†	33(^{15}N)	22†
T N (p)	90	0	35†	33†	22(^{15}N)

5LS : 5-leaf stage TS : Tillering stage PIS . Panicle initiation stage
† : Unlabeled urea

N uptake by rice plants

Total shoot dry matter showed no significant difference between nitrogen fertilization practice based on basal incorporation (BN) and nitrogen fertilization practice based on topdressing at 5-leaf stage (TN) before heading. Basal N

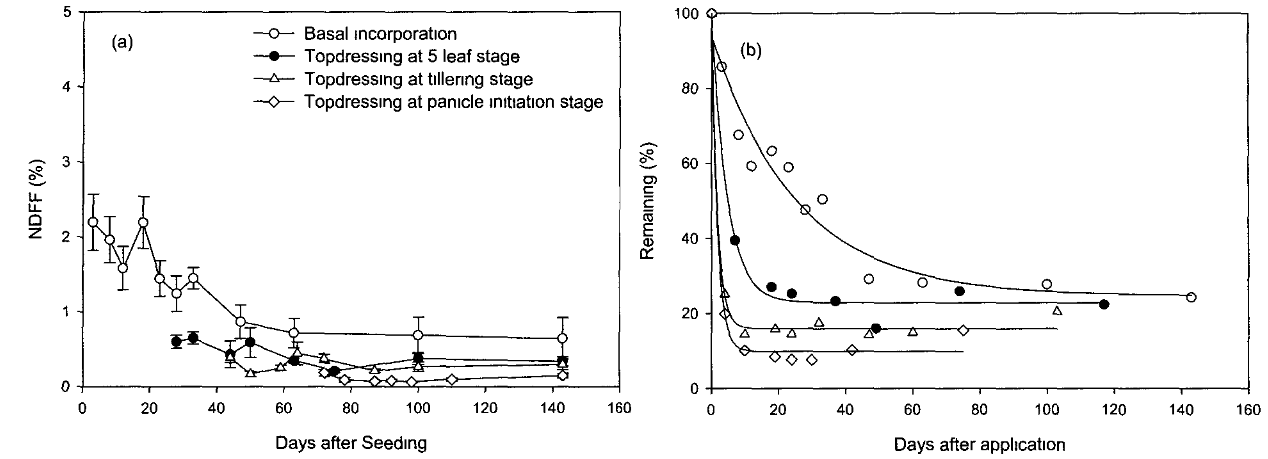

Fig. 1. Seasonal changes of (a) percent nitrogen derived from fertilizer (NDFF), and (b) remaining of fertilizer N applied with different N split applications in the soil

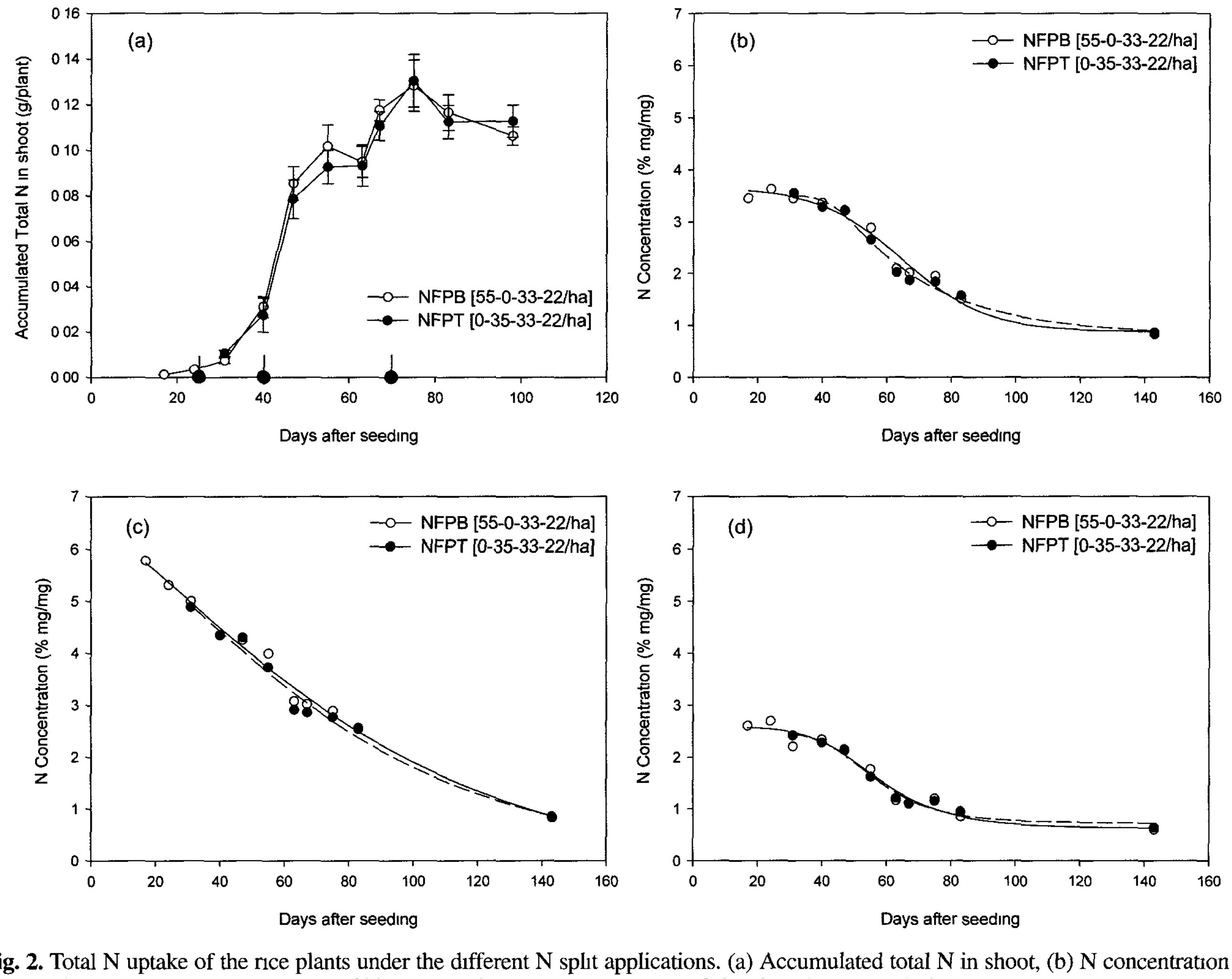

Fig. 2. Total N uptake of the rice plants under the different N split applications. (a) Accumulated total N in shoot, (b) N concentration in shoot, (c) N concentration in leaf blade, and (d) N concentration in leaf sheath and stem (● indicates topdressing timing).

was incorporated just before seeding, but it did not cause rice seedlings to accumulate more dry matter. It means that soil N was sufficient to support the earlier growth of rice plant until 4 or 5-leaf stage when the plant increased its dry matter gradually. According to Escabarte *et al.* (1999), dry weight of rice plant at all stages showed an exponential relationship with N uptake, irrespective of the cropping method and planting environment. The result suggested that the first topdressing timing should be 4 to 5 leaf stage when we designed a efficient N practice without basal N causing more N loss.

Plant N uptake kinetics followed a sigmoid pattern (Fig. 2). Total N in the plant increased rapidly during the tillering stage, and peaked at panicle differentiation stage, and thereafter declined slightly to stable at heading (a). Shoot N concentration decreased from crop establishment until maturity (b), and foliage N concentration decreased more rapidly (c). These uptake patterns were not significantly different between the two different N fertilization practices.

Uptake of fertilizer N

Fertilizer ^{15}N uptake from the basal N increased until 46 days after application, at which it peaked at 30.4 % of the applied N, but it was not remarkable until 20 days after application (Fig. 3). It stayed relatively constant from 46 days until heading after application. Fertilizer ^{15}N uptake from the top-dressed N at 5-leaf stage increased until 21 days after application, at which it peaked at 34.7% of the applied N. In basal incorporation, the duration of effective absorption was 2 days longer than that in topdressing at 5-leaf stage. On the other hand, fertilizer N uptake kinetic in 5-leaf stage was much effective to minimize N losses than that in basal incorporation.

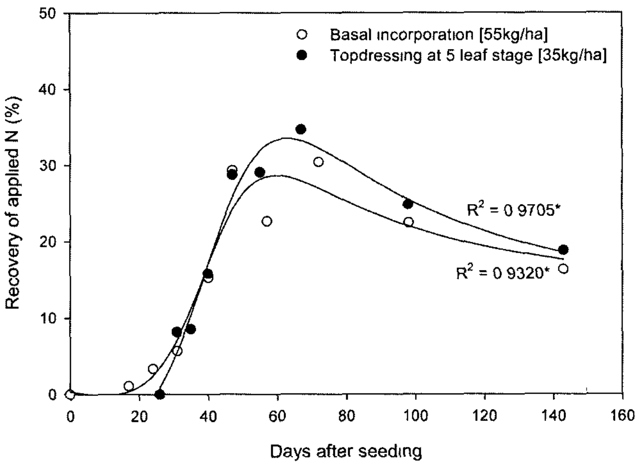

Fig. 3. Fertilizer N uptake and recovery of the rice plants under the different N split applications.

Table 2. Fertilizer ^{15}N recovered as affected by different N split applications and developmental stages.

Timing of application	Amount of N application	Plant part	Fertilizer ^{15}N recovered		
			Panicle formation	Heading	Maturity
	kg/ ha		--- % of applied N ---		
Basal	55	LB	20 20	11 30	3.20
		LS+S	10.20	9.74	5.37
		PN	-	1 39	7.78
		Total	30.40	22.43	16.35
5LS	35	LB	23.06	12 68	3.49
		LS+S	11.60	10.79	5 93
		PN	-	1.34	9.40
		Total	34.66	24 81	18.82
TS	33	LB	53 92	22 97	6 31
		LS+S	20.28	22.54	11.62
		PN	-	2 79	17.05
		Total	74.20	48.30	34.98
PIS	22	LB	51.96	37.45	7 75
		LS+S	35.14	32 72	16.11
		PN	-	5.33	23.37
		Total	87.10	75.50	47.23

5LS : 5-leaf stage TS . Tillering stage PIS : Panicle initiation stage
LB : Leaf blade LS+S : Leaf sheath and stem PN : Panicle

Recovery of fertilizer N

Fertılizer ^{15}N recovered ın the shoot with the different N split applications was different within the same developmental stage (Table 2). Recoveries of the basal N in shoot were 30.4% at panicle formation, 22.4% at heading, and 16.4% at maturity, respectively. Topdressing at 5-leaf stage resulted in recovery of 34.7% of the applied N in the shoot at panicle formation, 24.8% at heading, and 18.8% at maturity, respectively. This was higher than that of the basal N within other growth stages. Topdressing at tillering stage resulted in recovery of 74.2% of the applied N in the shoot at panicle formation, 48.3% at heading, and 35.0% at maturity, respectively. Topdressing at panicle initiation stage resulted in recovery of 87.1% of the applied N in shoot at panicle formation, 75.5% at heading, and 47.2% at maturity, respectively. The later the time of topdressing was, the more the top-dressed N was recovered. There were decreasing trend of fertilizer ^{15}N recovery during these period within all the application treatments.

Plant recoveries of fertilizer ^{15}N applied with different application stages were 7.8% for basal, 9.4% for 5-leaf stage, 17.1% for tillering stage, and 23.4% for panicle initiation stage, respectively (Table 3). When urea was applied with BN, plant recovery of ^{15}N at harvest was 31.0%, which was originated from 13.7% for grain, and 21.3% of the fertilizer ^{15}N remained in the soil, and the rest could be uncounted. Plant recovery of fertilizer ^{15}N applied with TN, where N rate was reduced by 18% compared with BN, was 35.1% (grain 15.6%), and 19.9% of the fertilizer ^{15}N remained in the soil, and the rest could be uncounted. TN showed a higher ^{15}N recovery than BN because it was to apply N fertilizer at a time to well meet the demand of rice plant direct-seeded on flooded paddy.

Nitrogen use efficiency

The grain yield increase from fertilizer N ranged from 296 kg ha^{-1} to 522 kg ha^{-1} depending on different N split applications (Table 4). Fertilizer N recovery efficiencies of top-

Table 3. Total Recovery of fertilizer N in soil-plant system for rice as affected by different N split applications

Fertilizer N application	Fertilizer ^{15}N recovered					
	Plant				Soil	Total
	Grain	Straw	Root	Total		
	------------------ % of applied N ------------------					
Basal (a1)	7 78	8.57	2.62	18 97	24 24	43 21
5LS (a2)	9.40	9 42	4.50	23 31	22 26	45 57
TS (b)	17.05	17.93	2.72	37.70	20.41	58 11
PIS (c)	23.37	23.86	3.68	50.92	15 46	66.38
BN (a1+b+c)	13 68	14 43	2.86	30.98	21.34	52.32
TN (a2+b+c)	15.59	15.90	3 65	35 14	19.92	55 06

5LS · 5-leaf stage TS : Tillering stage PIS : Panicle initiation stage
BN : N fertilization practice based on basal incorporation
TN : N fertilization practice based on topdressing at 5LS

Table 4. Nitrogen use efficiency in shoot as affected by different N managements.

Nitrogen management	N rate (kg/ ha)	Total N from fertilizer (kg/ ha)	Grain yield from fertilizer (kg/ ha)	Recovery efficiency (%)	Physiological efficiency (kg grain/ kg N uptake)	Agronomic efficiency (kg grain/ kg N applied)
Basal (a1)	55	9 0a	384.4c	16.4d	42.6b	7 0d
5LS (a2)	35	6 6b	295.7d	18 8c	44.9a	8 5c
TS (b)	33	11.5a	522.1a	35 0b	45 2a	15.8b
PIS (c)	22	10.4a	475 6b	47.2a	45.8a	21.6a
BN(a1+b+c)	110	30.9	1,382 1	28.1	44 7	12.6
TN(a2+b+c)	90	28 5	1,293 4	31 7	45.3	14 4

5LS : 5-leaf stage TS : Tillering stage PIS : Panicle initiation stage
BN Urea [55-0-33-22 N / ha] TN Urea [0-35-33-22 N / ha]
*Within a column, means followed by the same letter are not significantly different at p≤0 05 based on DMRT.

dressing were significantly higher than that of basal incorporation. The highest recovery efficiency was recorded in case of topdressing at panicle initiation stage within topdressing timings. Physiological efficiencies of topdressings were superior to that of basal incorporation, but there was not a significant difference within topdressing timings.

Agronomic efficiencies (increment of yield per unit applied N) of N fertilizer applied with different application timings were 7,0 for basal, 8.5 for 5-leaf stage, 15.8 for tillering stage, and 21.6 for panicle initiation stage, respectively. As a result, TN showed a higher agronomic efficiency than BN. Therefore, we could conclude that TN would be the efficient method to reduce N losses without reducing yields.

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