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Effects of Urease Inhibitor, Nitrification Inhibitor, and Slow-release Fertilizer on Nitrogen Fertilizer Loss in Direct-Seeding Rice

Jae Hong Lee*†, Ho Jin Lee*, and Byun-Woo Lee

ABSTRACT

To study the effects of an urease inhibitor, N-(*n*-butyl)-thiophosphoric triamide (NBPT), and a nitrification inhibitor, dicyandiamide (DCD), on nitrogen losses and nitrogen use efficiency, urea fertilizer with or without inhibitors and slow-release fertilizer (synthetic thermoplastic resins coated urea) were applied to direct-seeded flooded rice fields in 1998. In the urea and the urea+DCD treatments, NH_4^+-N concentrations reached 50 mg N L^{-1} after application. Urea+NBPT and urea+NBPT+DCD treatments maintained NH_4^+-N concentrations below 10 mg N L^{-1} in the floodwater, while the slow-release fertilizer application maintained the lowest concentration of NH_4^+-N in floodwater. The ammonia losses of urea+NBPT and urea+NBPT+DCD treatments were lower than those of urea and urea+DCD treatments during the 30 days after fertilizer application. It was found that N loss due to ammonia volatilization was minimized in the treatments of NBPT with urea and the slow-release fertilizer. The volatile loss of urea+DCD treatment was not significantly different from that of urea surface application. It was found that NBPT delayed urea hydrolysis and then decreased losses due to ammonia volatilization. DCD, a nitrification inhibitor, had no significant effect on ammonia loss under flooded conditions. The slow-release fertilizer application reduced ammonia volatilization loss most effectively. As NO_3^--N concentrations in the soil water indicated that leaching losses of N were negligible, DCD was not effective in inhibiting nitrification in the flooded soil. The amount of N in plants was especially low in the slow-release fertilizer treatment during the early growth stage for 15 days after fertilization. The amount of N in the rice plants, however, was higher in the slow-release fertilizer treatment than in other treatments at harvest. Grain yields in the treatments of slow-release fertilizer, urea+NBPT+ DCD and urea+NBPT were significantly higher than those in the treatments of urea and urea+DCD. NBPT treatment with urea and the slow-release fertilizer application were effective in both reducing nitrogen losses and increasing grain yield by improving N use efficiency in direct-seeded flooded rice field.

Keywords : direct seeding, rice, slow- release fertilizer, urease inhibitor, nitrification inhibitor, NBPT (N-(*n*-butyl)-thiophosphoric triamide), DCD (dicyandiamide), ammonia volatilization, N loss, nitrogen use efficiency.

Urea is the main N fertilizer used for flooded rice in Asia, but it has been used inefficiently. N recovery rarely exceeds 30~40% in wetland rice production regions. The main reason for the poor efficiency is that large quantities of N are lost from the flooded soil system. Direct-seeded flooded rice is a good way to save labor in rice cultivation. However, it is recommended to maintain drainage for about 4 days after basal application for the best soil condition for seeding. After seeding, it is necessary to irrigate immediately and maintain flooded conditions during the emergence period and drain repeatedly to improve the seedling stand. This type of water management provides favorable conditions for urea N loss due to ammonia volatilization, nitrification, and denitrification. Use of urease inhibitors would offer considerable potential for increasing the efficiency of urea fertilizer application (Buresh et al., 1988a). The high ammoniacal N concentrations combined with the elevated floodwater pH during daylight hours result in large losses of N through ammonia volatilization. Retarding urea hydrolysis at the soil surface will allow urea to be transported to deeper soil layers before it is hydrolyzed; ammonium released then would be retained by the cation exchange complex in the soil. This approach was used successfully in laboratory and glasshouse experiments with the compounds phenylphosphorodiamidate (PPD) and N-(*n*-butyl)-thiophosphoric triamide (NBPT), the most successful of the urease inhibitors so far developed (Cai et al., 1989). However, in field experiments, applications of these urease inhibitors to flooded rice have seldom resulted in increased grain yields (Buresh et al., 1988b, Simpson et al., 1985).

Nitrification inhibitors are defined as compounds or materials that specifically retard the oxidation of ammonium to nitrite without affecting the subsequent oxidation of nitrite to nitrate (Sahrawat, 1989). Since retardation of nitrification increases the persistence of ammonium in soils, it must be expected that

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* Department of Agronomy, Seoul National University.

*† Corresponding author : (E-mail) jlee 9197@hanmail.net (Phone)+82-331-290-2315. Recieved 22 July, 1999.

retardation of nitrification affects ammonium nitrogen transformation processes such as fixation or adsorption and volatilization in some situations. Also retardation of nitrification may result overall in less movement and transport of mineral nitrogen because of higher NH_4^+/NO_3^- ratios in soils caused by retardation of nitrification (Sahrawat and Keeney, 1984).

By using specific fertilizer formulations to release N in synchrony with plant growth, slow-release fertilizer would possibly provide sufficient N in a single application to satisfy plant requirements yet maintain very low concentrations of mineral N in the soil throughout the growing season. With this concept, any gaseous loss event would be small because of the limited substrate (Bacon, 1995). The amount of N in the plants was higher in the slow-release fertilizer applied plots due to the higher percentage recovery of basal N and the enhanced yield by the slow-release fertilizer application could be attributed to an increase in sink size (Genshichi et al., 1991). Our previous research on N split application indicated some improvements in N efficiency in direct-seeded rice (Lee et al., 1998).

The objectives of this research were to evaluate the effects of slow-release fertilizers, urease inhibitors and nitrification inhibitors on fertilizer N losses, transformations, and N use efficiency when urea was applied to direct-seeded flooded rice.

MATERIALS AND METHODS

The experiment was conducted on loam soil in a paddy field at College Farm, Seoul National University, Suwon in 1998(Table 1). The experimental plots were ploughed, flooded and harrowed to puddle and level the paddy field. The experimental plots were laid in a completely randomized design with three replications. Phosphate and potash were applied as starter fertilizer at a rate of 8 kg/10a, respectively. The rice cultivar, 'Hwasungbyeo', was direct-seeded at 4kg dry seed per 10a in rows using an 6-row drill planter at 30cm spacing on 20 May.

NBPT and DCD were added as 5% of the weight of urea. Urea and slow-release fertilizer (5kg N/10a) were surface applicated on 17 June at the 4-leaf stage. Meister 10, polyolefin-coated urea was used as a slow-release fertilizer. N fertilizer sources and treatments are shown in Table 2. The split N application was conducted on 18 July and 5 August, respectively.

Floodwater samples were taken from three sites within each plot and analyzed for NH_4^+-N by the indophenol method. Soil water was sampled at 20, 40cm depth from the soil surface with vacuum pressure water sampler and filtered with Watman no. 42 filter paper. NO_3^--N in the filtered water was determined colorimeterically. Soil was sampled with a

Table 1. Soil characteristics of experimental field.

Soil particle distribution(%)			Texture (USDA)	pH†	Cation exchange capacity(cmol/kg)				Organic matter (%)	Total N content (mg/g)
Sand	Silt	Clay			CEC	Ca^{2+}	K^+	Mg^{2+}		
41	35	24	Loam	5.8	4.6	3.3	0.3	0.2	1.72	1.3

†. 1:5, w/v H_2O

Table 2. Treatments with inhibitors and N Fertilization method.

Treatment	Split N Fertilizer application		
	1st application(17 Jun.)	2nd app.(18 Jul.)	3rd app.(5 Aug.)
Urea	Urea(5 kg N/10a)	Urea(3 kg N/10a)	Urea(2 kg N/10a)
Urea+ NBPT	Urea(5 kg N/10a)+ NBPT(5% w/w to urea)	Urea(3 kg N/10a)	Urea(2 kg N/10a)
Urea+ DCD	Urea(5 kg N/10a)+ DCD(5% w/w to urea)	Urea(3 kg N/10a)	Urea(2 kg N/10a)
Urea+ NBPT+ DCD	Urea(5 kg N/10a)+ NBPT(5% w/w to urea)+ DCD(5% w/w to urea)	Urea(3 kg N/10a)	Urea(2 kg N/10a)
Slow-release fertilizer	Polyolefin-coated urea (5 kg N/10a)	Urea(3 kg N/10a)	Urea(2 kg N/10a)

soil auger and sectioned into 0~3cm and 3~15cm layers. A sample of the wet soil was shaken with 100ml of 2M KCl-PMA solution for 1 hour. The mixture was then filtered and analyzed for NH_4^+-N by distillation (Bremner, 1965b). Plant materials were dried in an oven at 65℃ for 48 hours and their total N was determined using the Kjeldahl method (Bremner, 1965a). A semi-open static system (Nommik, 1973) was adapted to measure NH_3 volatilization losses from the plots. Ammonia trapping chambers constructed of PVC pipe pipes (20.5cm inner diameter) were placed over the treated plots. The chambers were painted white to reduce temperature build-up within them. Each chamber held two polyu rethane foam sponges. The upper sponge acts as a scrubber preventing atmospheric NH_3 from entering the chamber; the lower sponge trapped NH_3 evolving from the floodwater. The sponges were wetted with 0.7M H_3PO_4 solution containing 50%(v/v) glycerol. Every sampling time, the chambers were moved to a different place in the same plot and the lower sponge was removed, placed in a plastic bag, and replaced with a fresh H_3PO_4- glycerol wetted sponge. The collected sponges were extracted with 200ml of 2M KCl solution and analyzed for NH_4^+-N by distillation.

RESULTS

Floodwater ammonium

The floodwater NH_4^+-N concentrations after the fertilizer application increased and reached maximum concentration on the first day after application and then gradually decreased (Fig. 3). In the urea and the urea+DCD treatments, NH_4^+-N concentrations reached 50 mg N L^{-1} after urea fertilizer application. Urea+NBPT and urea+NBPT+DCD treatments maintained NH_4^+-N concentrations in floodwater below 10 mg N L^{-1}, while the slow-release fertilizer application maintained the lowest concentration of NH_4^+-N below 5 mg N L^{-1}. It thus appeared that NBPT had a beneficial effect in lowering the NH_4^+-N concentrations in floodwater for about 10 days. DCD treatment had no effect on decreasing NH_4^+-N concentration in the floodwater.

Ammonia losses

In wetland rice fields, the floodwater ammoniacal-N (NH_4^++NH_3) concentrations following N application, high temperature, and elevated floodwater pH resulting from algal photosynthetic activity create a favorable environment for NH_3 loss. Aqueous NH_3 in floodwater increased about tenfold per unit increase in pH in the range 7.5~9.0 (Vlek and Stumpe, 1978). Vlek and Craswell (1981) reported that aqueous NH_3 content in floodwater increased almost linearly with increasing temperature, which results in nearly a fourfold increase in the range from 10 to 40℃.

Daily NH_3 volatilization losses in the urea treatment were higher initially than those in the urea+DCD, but this was reversed later so that the cumulative amounts of NH_3 volatilization losses from the two treatments were nearly the same (Fig. 2). The NH_4^+-N concentrations in the urea and the urea+DCD treatments were the highest and the amount of cumulative NH_3 loss was the largest for the 30-day period after urea fertilizer application (Fig. 1, 2). However, cumulative NH_3 volatilization losses were reduced in urea+NBPT and urea+NBPT+DCD treatments by inhibition of urea hydrolysis. The slow-release fertilizer application effectively reduced ammonia volatilization loss because of the lowest NH_4^+-N concentration in floodwater (Fig. 1, 2). These results showed that the elevated NH_4^+-N concentrations in floodwater after the application of N fertilizer highlight the potential for NH_3 volatilization.

Soil Ammonium and soil water nitrate

The content of NH_4^+-N in each soil layer increased after fertilizer application. The peaks, at about 5 days after fertilization in urea and urea+DCD treatments and at about 12 days after fertilization for slow-

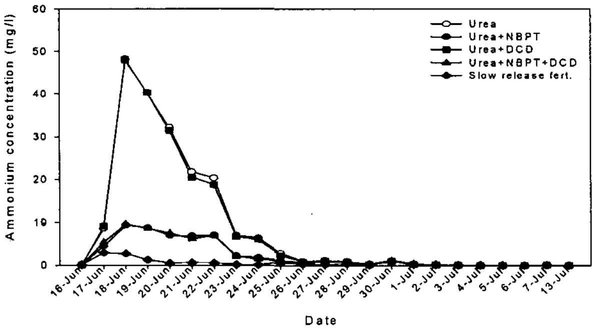

Fig. 1. Ammonium-N concentration in floodwater after starter N application.

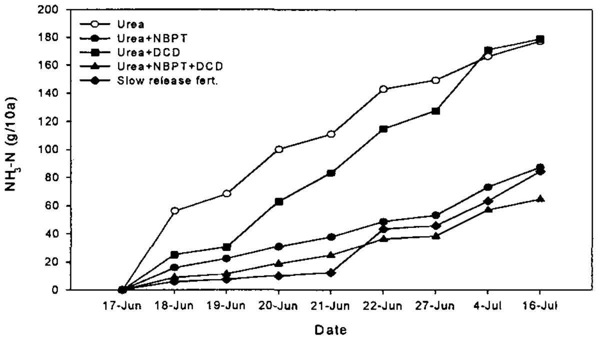

Fig. 2. Cumulative ammonia volatilization losses determined by semiopen-static system.

release fertilizer, urea+NBPT and urea+NBPT+DCD, are due to the slow release of NH_4^+-N from the applied N fertilizer. The maximum contents of NH_4^+-N in the soil of urea treatment and urea+DCD were observed at 5 days after fertilization and declined rapidly. On the other hand, the soil NH_4^+-N contents in slow-release fertilizer, urea+NBPT and urea+NBPT+DCD treatments remained relatively high until the next application (Fig. 3, 4). The slow declinations of NH_4 -N contents accumulated to the same amount of NH_4 -N retained in the soil by using NBPT and slow-release fertilizer.

Changes in NO_3^--N concentration in soil water at 20, 40cm depth are shown in Fig. 5 and Fig. 6. NO_3 -N concentrations in the soil water of all treatments were low, usually less than 2 mg L^{-1}, with a maximum of 3 mg L^{-1} because of anaerobic soil conditions. These results indicated that leaching losses of N were negligible and DCD was not effective in inhibiting nitrification in the flooded soil condition.

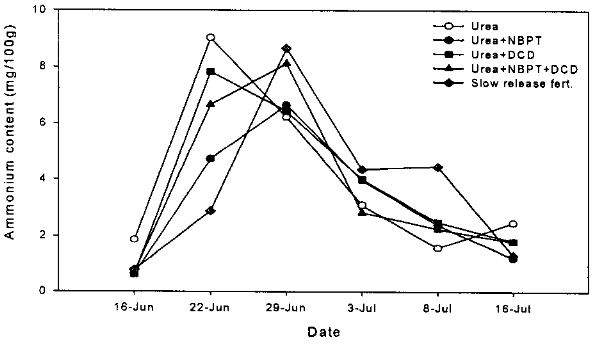

Fig. 3. Changes of extractable ammonium-N content in surface soil at 0-3cm depth.

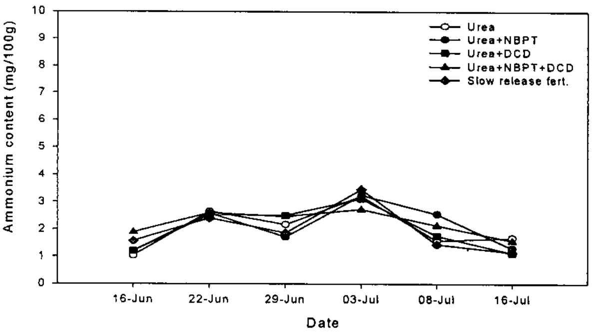

Fig. 4. Changes of extractable ammonium-N content in surface soil at 3-15cm depth.

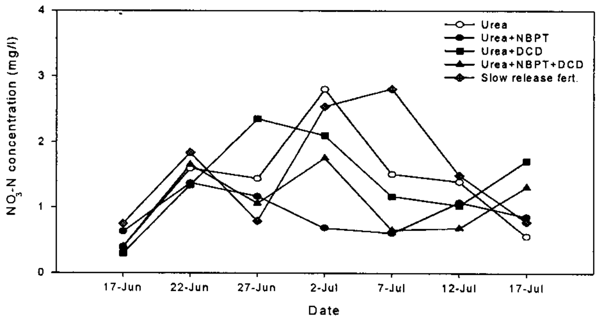

Fig. 5. Changes in NO_3^--N concentration in paddy soil water at 20cm depth.

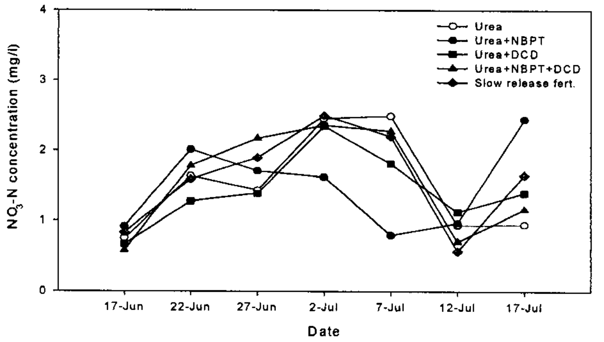

Fig. 6. Changes in NO_3^--N concentration in paddy soil water at 40cm depth.

N absorption by rice plant

The differences of N content in plant shoot and root among these treatments were not statistically significant at 15, 30 days after treatments. Dry weight of plant shoot, plant height and total N uptake in above ground plants were significantly low in the slow-release fertilizer treatment at 15 days after fertilization. The dry weight of plant shoots and total N uptake in above ground plants, however, were not significantly different in all treatments at 30 days after fertilization. For all treatments, plant heights were significantly different, although those for the urea and slow-release fertilizer treatments were rather low at 30 days after fertilization. The early differences in the dry weight of shoots and N uptake amounts in the above ground plants among the different treatments were not found at 30 days after fertilization.

Yield and N use efficiency

Grain yields ranged from 626 kg/10a for urea treatment to 690 kg/10a for the slow-release fertilizer treatment. Grain yield was significantly low in the urea treatment. Significantly high yields were obtained in the slow-release fertilizer, urea+NBPT+DCD and urea+NBPT treatments. The yield differences among these three treatments were not statistically significant. In yield components, number of spikelets per panicle in the slow-release fertilizer treatment was

Table 3. Plant dry weight and N content in plant shoot and root at 15 days after treatment.

Treatment	15 days after fertilizer application				Total N uptake amount† (mg N/plant)
	N content in plant shoot (mg N/g)	N content in plant root (mg N/g)	Dry wt. of plant shoot (mg/plant)	Plant height (cm)	
U	32.62	11.28	0.67ab	40.8a	21.90ab
U+N	34.93	10.39	0.68a	42.1a	23.75a
U+D	31.68	10.53	0.70a	41.1a	22.17a
U+N+D	35.27	11.96	0.56b	41.7a	19.75b
SRF	33.17	12.13	0.43c	38.0b	14.26c
F value	2.00ns	1.05ns	8.55*	13.11**	27.86**

†; N content in above ground plant × D.W. / plant
ns; Not significant at P=0.05.
*, **; Significant at the 0.05 and 0.01 probability levels, respectively.

Table 4. Plant Dry weight and N content in plant shoot and root at 30 days after treatment.

Treatment	30 days after fertilizer application				Total N uptake amount† (mg N/plant)
	N content in plant shoot (mg N/g)	N content in Plant Root (mg N/g)	Dry wt. of plant shoot (mg/plant)	Plant height (cm)	
U	18.97	10.41	1.34	60.2b	25.42
U+N	20.46	10.37	1.51	62.3a	30.89
U+D	18.81	9.94	1.59	62.9a	29.90
U+N+D	20.96	9.74	1.80	62.2a	37.74
SRF	20.58	11.09	1.37	59.5b	28.19
F value	0.33ns	0.67ns	4.75ns	5.57**	3.25ns

†; N content in above ground plant × D.W. / plant
ns; Not significant at P=0.05.
*, **; Significant at the 0.05 and 0.01 probability levels, respectively.

Table 5. Comparison of grain yield and its components.

Treatment	No. of panicles/m^2	No. of spikelets/panicle	Ripened grains(%)	1000 grain wt. (g)	Grain yield (kg/10a)
Urea	325.8	74.6b	95.6a	26.3	625.5b
Urea+NBPT	349.8	75.0b	96.1a	26.9	677.1a
Urea+DCD	336.6	71.2c	96.1a	26.7	638.0ab
Urea+NBPT+DCD	359.2	76.7b	93.3b	26.4	684.8a
Slow-release fert.	331.9	82.2a	93.7b	26.2	689.6a
F value	2.58ns	13.76**	9.63*	0.76ns	3.08*

ns; Not significant at P=0.05.
*, **; Significant at the 0.05 and 0.01 probability levels, respectively.

Table 6. Effect of nitrogen fertilizers and inhibitors on Nitrogen use efficiency, Uptake Efficiency and Utilization Efficiency.

Treatment	N fert. added† (kgN/10a)	Plant N‡ (kgN/10a)	Grain yield (kg/10a)	Uptake Efficiency§	Utilization Efficiency¶	N use Efficiency#
Urea	10	10.88	625.5	1.09	57.5	62.6
Urea+NBPT	10	12.70	677.1	1.27	53.3	67.7
Urea+DCD	10	12.70	638.0	1.11	57.6	63.8
Urea+NBPT+DCD	10	13.31	684.8	1.33	51.5	68.5
Slow-release fert.	10	13.58	689.6	1.36	50.8	69.0

†; N added as fertilizer , ‡; N removed in above ground part
§; Uptake Efficiency = Plant N / N fert. added
¶: Utilization Efficiency = Grain yield / Plant N
#: N use Efficiency = Grain yield / N fert. added

higher compared to the other treatments.

Nitrogen use efficiency and uptake efficiency were high in the slow-release fertilizer treatment because of its high N content in plant and high grain yield. NBPT treatment with urea and slow-release fertilizer application were effective in both reducing nitrogen losses and increasing grain yield by improving N use efficiency in direct-seeded flooded rice fields.

DISCUSSION

The extensive losses of applied N from the paddy soil system are the sum of volatilization loss and leaching loss, resulting in environmental contamination.

The rate of NH_3 volatilization loss is dependent on the pH and temperature as well as on ammoniacal-N concentration (Vlek and Craswell. 1981). Ammonia volatilization loss amounts were measured in low floodwater temperature and pH conditions in terms of actual field conditions. The temperature of the floodwater at mid-day was 1 to 4℃ lower inside the ammonia trapping chamber than that of outside the ammonia trapping chamber. Also, the pH of the floodwater outside the ammonia trapping chamber fluctuated between pH 7.4 and pH 8.7 with a diurnal pattern but the floodwater pH inside the ammonia trapping chamber did not fluctuate(Data not shown). Therefore, we must admit that our measured NH_3 volatilization loss amounts were under-estimated to a certain extent.

It was considered that the beneficial effect of NBPT on reducing N loss was due to the inhibition of urease in the floodwater which allowed more unhydrolyzed urea to penetrate beyond the soil surface and to be hydrolyzed slowly in the reduced soil layer. DCD was not effective in inhibiting nitrification in the flooded soil. Simpson *et al.* (1985) also showed that DCD was not effective in inhibiting nitrification under the flood condition. Slow-release fertilizer application resulted in increased grain yield and N use efficiency, and the effect of this fertilizer was due to the delayed NH_4^+ releasing pattern until the late growth stage of rice. Thermoplastic resin-coated urea had been developed as a slow-release fertilizer. The resin coating is primarily a blend of polyolefin-type resin, EVA copolymer, and polyvinylidene chloride type resin as major components. Polyolefin-coated urea is a controlled-release granular fertilizer whose dissolution is primarily temperature-dependent. Dissolution doubles for every 10℃ rise in temperature, a Q_{10} matching that of plants (Gandeza et al., 1991, Shoji et al., 1991). Slow-release fertilizer, Meister 15, applied into the whole layer showed better rice growth and nitrogen use efficiency than conventional fertilizer (Park, 1993). Slow-release fertilizer could be an effective means for reducing N loss and improving N uptake.

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