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稻田脲酶抑制剂对尿素N利用效率的影响

IMPACT OF UREASE INHIBITORS ON UTILIZATION EFFICIENCY OF N-UREA IN RICE PADDY

(*In Chinese*)

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稻田脲酶抑制剂对尿素 N 利用效率的影响

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摘　要

尿素施入稻田后迅速水解成 NH_4^+，两天后水层中 NH_4^+-N 含量即达峰值，混施脲酶抑制剂峰值可推迟一天出现，并可降低其峰高。^{15}N 示踪试验表明：PPD 和 NBPT 两种抑制剂能明显地促进水稻氮素的吸收和水稻生长，提高尿素氮的利用率，减少损失率，并在一定程度上具有增产效果，尤其是在高氮水平下以上效果更为明显，而抑制剂 HQ 则较差。稻草的施用对水稻生长有一定的影响，降低了水稻对肥料氮素的吸收，但能提高肥料氮素在土壤中的残留量。

Impact of Urease Inhibitors on Utilization Efficiency of N-Urea in Rice Paddy

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ABSTRACT

Urea applied to the paddy field rapidly released ammonium (NH_4^+) through hydrolysis. The released NH_4^+-N was usually at peak two days after the application. The peak was found to be lower and delay one day when a mixture of urea and urease inhibitors was applied. Based on tracing of ^{15}N in the urea used, the two urease inhibitors, phenylphosphordiamidate (PPD) and N- (N-butyl) thiophosphoric triamide (NBPT), were found to enhance the efficiency of urea utilization by rice plants due to more absorption and also stimulate rice growth. The grain yields in the treatments applied with the mixture containing PPD or NBPT were higher, particularly at high N level, than that in the treatment applied with urea only. However, the urea inhibitor, hydroquinone (HQ), displayed far less effect than PPD and NBPT in the experiment. The application of rice straw was found to decrease the absorption of rice plants to N in urea but increase its residue in the soil.

INTRODUCTION

As an important nitrogen fertilizer, the urea applied to the paddy field is usually transformed into $(NH_2)_2CO_2$ via the action of the ureases in soil. The activity of the ureases also affects the rate of the transformation. In general, the activity of the ureases is associated with the richness of organic matter in the soil as well as the composition of the organic matter. The increase of the NH_4^+-N concentration in water may rapidly enhance the pH value, causing the NH_4^+ loss and reducing the nitrogen utilization. The nitrogen utilization of urea in the paddy field was reported only from 25% to 40% (Liu and Qiu, 1994). Thus, it is concerned about the enhancement of urea N utilization in the paddy field.

One of the methods used to delay the hydrolysis of the urea after application was the use of urease inhibitors with the urea (Lu and Chen, 1992). The urease inhibitors that make the ureases inactive were found to reduce the hydrolysis rate of the urea and the concentration of NH_4^+-N in water (Zhao, 1998; Zhou, 1984) and balance between the N absorption of rice and the N aupply of soil for higher N utilization of the urea by rice plants (Lu et al., 1989). Also, the use of the urease inhibitors could reduce the loss of ammonium (NH_4^+) and its pollution to environment.

The two urease inhibitors, phenylphosphordiamidate (PPD) and N- (N-butyl) thiophosphoric triamide (NBPT), were highly effective in reducing the urea hydrolysis , the NH_4^+-N concentration and the pH value in the paddy water (Buresh, 1988). However, their action was affected by various factors such as chemi-physical nature of soil, environmental temperature, organic matter, and application techniques. This paper presents data on the efficiency of three urease inhibitors (including PPD and NBPT) for nitrogen balance during rice growth in potted and plotted experiments.

1 MATERIALS AND METHODS

The materials used included three urease inhibitors, PPD, NBPT (IFDC) and hydroquinone (HQ, Hongzhou Chemical Reagent Company), and tracing urea, $(^{15}NH_2)_2CO$ (^{15}N abundance of 10.11%, Shanghai Chemical Institute), The soil used for the growth of potted plants was red earth (Qu County, Zhejiang, pH 6.1, organic carbon 11.46 g • kg^{-1} and total nitrogen 1.39 g • kg^{-1}). The soil used for the plotted field experiment was blue mud (pH6.9, organic carbon 24.2 g • kg^{-1}

and total nitrogen 2.59 g • kg^{-1}). The rice variety was japonica Zhong-156.

1.1 Plotted field experiment

The field for plots (21 m^2 each) was located on the experiment farm of China National Rice Research Institute (CNRRI), Fuyang, Zhejiang. Rice plants (31 d-old) were transplanted on May 11. The experiment included five treatments: (1) PPD+urea; (2) NBPT+urea; (3) HQ+urea; (4) urea only (UO); and (5) CK (no urea, no urease inhibitor). All treatments with 4 replicates were arranged in random. All plots except CK were supplied with base fertilizers including urea-N of 40 kg • hm^{-2}, KCl of 150 kg • hm^{-2}, and calcium superphosphate 375 kg • hm^{-2}. 80 kg of urea-N per hectare was applied to each treatment for top-dressing 10 d after transplanting. Each urease inhibitor was mixed with 1% urea (mass fraction) for base and topdressing. The concentrations of urea-N and NH_4^+-N in the paddy water were measured using 1 (Mulvaney and Bremner, 1979) and 2 in samples taken 1, 2, 3, 4, 5, 7, and 14 d after topdressing, respectively.

1.2 Potted experiment

Three hills of rice plants (31 d-old, 3 plants per hill) were transplanted in each pot (20 cm in height and diameter) filled with 4 kg naturally dried red earth (passed 2 mm screen) on May 11. Each pot was supplied with P (75 mg • kg^{-1}) and K (100 mg • kg^{-1}) for base. The nitrogen, ^{15}N-urea, was used as base (50%) and topdressing (50%). Each urease inhibitor was used in a mixture with 1.5% ^{15}N-urea (mass fraction) for base and topdressing, respectively. The experiment included two parts as follows.

Part 1 was designed to test the effect of rice straw and the urease inhibitors on the balance of the nitrogen applied. It included 5 primary treatments (PPD+urea, NBPT+urea, HQ+urea, UO, and CK) and 2 secondory treatments containing or not containing rice straw. All treatments with 4 replicates were arranged in split random block design. The total of nitrogen used was 100 mg per kilogram of naturally dried soil. The rice straw was used as base in a mixture with 0.15% soil (mass fraction).

Part 2 was designed to test the effect of nitrogen application levels on the action of the urease inhibitors. It included 4 primary treatments: 50 (N_1), 100 (N_2), 150(N_3), and 200(N_4) mg of urea-^{15}N per kilogram of the soil, respectively. Four secondary treatments were PPD, NBPT, HQ and UO. All treatments were replicated 4 times and arranged in split randon block design.

All potted plants were harvested at the stage of ripening (July 29). The percentage of total nitrogen and ^{15}N abundance in the samples of the straw, grain, and soil were measured using Kjeitec Auto 1030 Analyzer (Tecator, Sweden) and mass spectrometry on Delta E (Finnigan MAT, Germany), respectively.

2 RESULTS AND DISCUSSION

2.1 Effect of urease inhibitors on the inhibition of urea hydrolysis

The concentration of NH_4^+-N in the paddy water was found greatly affecting the loss of NH_3 in the plotted experiments. As shown in Table 1, the concentration of $(NH_2)_2CO$-N was undetectable 1 week after topdressing due to the rapid hydrolysis of the urea applied in the field. However, the concentration of NH_4^+-N in the water inreased fast, reaching the peak 2-3 d after topdressing. Thereafter, the concentration of NH_4^+-N in the treatments gradually declined and became almost the same as that detected in CK 2 week after topdressing.

The effect of the urease inhibitors on the concentration of NH_4^+-N in the water was conspicuous. For instance, the peak of NH_4^+-N concentration occurred in the UO treatment (17.5 $\mu g \cdot ml^{-1}$) 2 d after topdressing but delayed 1 d in the treatments including the three urease inhibitors. Moreover, the pcak ranged from 10.03 to 15.58 $\mu g \cdot ml^{-1}$ in the treatments of the urease inhibitors, being lower than that in the UO treatment. The concentration of $(NH_2)_2CO$-N was also higher in the treatments with the urease inhibitors than that in the UO treatment (see Table 1), particularly during the first three days after topdressing.

Based the measurements of NH_4^+-N and $(NH_2)_2CO$-N, PPD was far more effective in inhibition of urea hydrolysis than NBPT and HQ in the paddy field.

Table 1 Effect of urease inhibitors on concentration of $(NH_2)_2CO$-N and NH_4^+-N in paddy water/$\mu g \cdot ml^{-1}$

Treatment	Days after topdressing							
	1	2	3	4	5	7	10	14
				NH_4^+-N				
PPD	0.76	2.30	10.03	10.00	6.14	2.00	1.50	0.64
NBPT	6.93	12.20	12.85	10.41	9.64	2.43	2.05	0.50
HQ	9.75	13.93	15.58	9.61	5.58	3.03	0.90	0.36
UO	7.27	17.50	13.88	10.24	7.05	2.89	1.53	0.51
CK	0.52	0.56	0.70	0.75	0.53	0.35	0.36	0.38
				$(NH_2)_2CO$-N				
PPD	90.60	31.25	12.95	4.83	1.34	0.51	0.00	
NBPT	82.06	25.14	11.51	4.25	1.69	0.52	0.00	
HQ	51.88	14.22	7.07	2.56	1.01	0.00		
UO	53.71	12.45	7.11	2.53	0.64	0.00		

2. 2 Effect of rice straw on the action of the urease inhibitors

Based on data from part 1 of the potted experiment (see Table 2), the treatments with the straw produced lower ground-above biomass of 18. 4% and grain of 25. 7% than the treatments without the straw. The three urease inhibitors could reduce the inverse effect of the straw on rice growth but their action differed from one another. PPD and NBPT were more effective than HQ.

Table 2 The effect of the three urease inhibitors on agronomic characteristics of rice at the same level of urea application

Treatment	Grain weigh/g · pot^{-1}		Shoot biomass/g · pot^{-1}		Grain/straw (mass fraction)	
	No straw	Straw	No straw	Straw	No straw	Straw
PPD	34. 7	32. 4	63. 3	58. 8	1. 21	1. 23
NBPT	30. 6	35. 1	58. 4	60. 1	1. 10	1. 41
HQ	29. 6	14. 1	55. 2	36. 1	1. 16	0. 64
UO	26. 6	10. 2	52. 0	29. 6	1. 05	0. 53
CK	7. 9	4. 4	20. 8	19. 1	0. 62	0. 30

The straw also affected the uptake of nitrogen by the rice plants. As shown in Table 3, each pot of the plants in average uptake was 596. 0 mg of nitrogen from the environment and 203. 8 mg from the ^{15}N-urea applied in the treatments without the straw. The same measurements for the treatments with the straw were 492. 8 mg and 137. 8 mg, decreasing 17. 3% and 32. 4%, respectively. The use of the urease inhibitors could greatly enhance the uptake of nitrogen from environment and the fertilizer applied and favor the transporting of the nitrogen from plants to grains. The averages of N and urea-^{15}N uptake by the plants from the treatment with PPD were 31. 2% and 36. 6% higher than those from the UO treatment, resulting in 19. 9% increase of N in grains.

Table 3 Effect of urease inhibitors on absorption of rice plants to N at the same level of ures

Treatment	Total uptake of N in plant/mg · pot^{-1}		Grain N / total N (mass fraction)		Uptake of fertilizer N /mg · pot^{-1}	
	No straw	Straw	No straw	Straw	No straw	Straw
PPD	780	696	0. 69	0. 67	238	177
NBPT	707	710	0. 66	0. 71	227	175
HQ	620	459	0. 67	0. 51	184	102
UO	594	421	0. 63	0. 46	166	97
CK	234	178	0. 38	0. 31	/	/

Nitrogen fertilizer uaually has three fates after being applied to the field. First, it may be absorbed or utilized by the crop. Second, it may remain in the soil for utilization by the following crop. Third, it may be lost in the gaseous forms of NH_3, N_2O and N_2 primarily due to volatization or antinitrification. The straw and the urease inhibitors applied to the field in large degree had an influence on the fate of the nitrogen used (Chen and Chen, 1990; Xu et al., 1989). In the present study, the percentages of the nitrogen (tracing ^{15}N) utilized by rice and lost in the environment were 24.24% and 46.7% in the UO treatment plus straw but were 41.4% and 41.8% in the UO treatment without straw (see Fig. 1). Apparently, the straw caused the increase of the nitorgen loss and the decrease of the nitrogen utilization. On the other hand, the ^{15}N residue in the UO treatment plus straw reached 29.1% whereas the residue in the UO treatment without straw was only 17.2%. This indicates that the application of the straw could greatly enhance the ^{15}N residue.

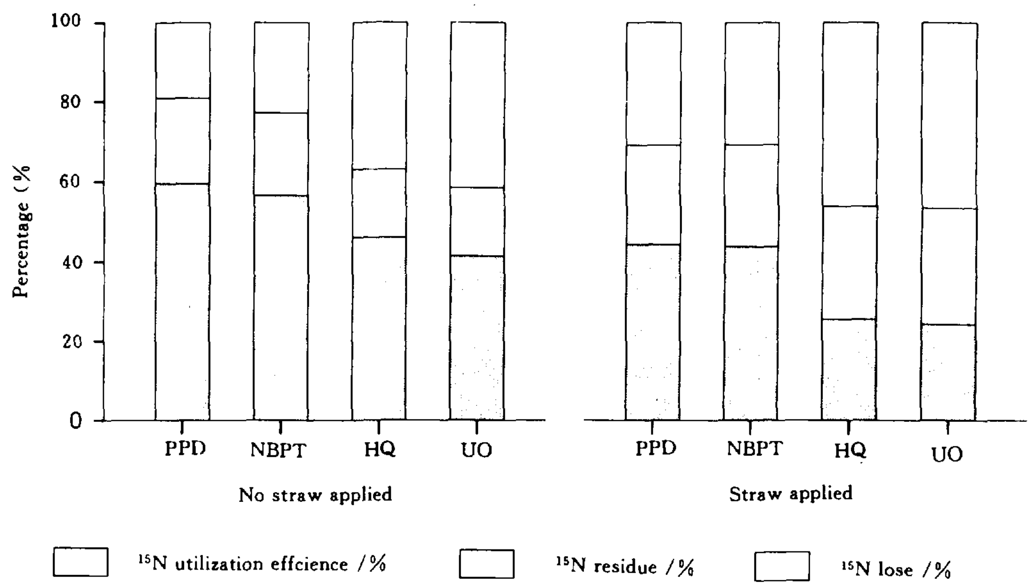

Fig. 1 Effect of urease inhibitors on ^{15}N-urea fate

In the lack of the straw, the treatments plus the urease inhibitors resulted in a higher percentage of the utilization of the ^{15}N by rice (by 4.7%~18.1%) and a lower percentage of the loss (by 4.9%~22.8%) than the UO treatments. The ^{15}N residue also increased due to the existence of the urease inhibitors. Moreover, the use of the urease inhibitors was found to some extent counteracting the inverse effect of the application of the straw on the utilization of the nitrogen applied. PPD was most effective among the urease inhibitors tested.

2.3 Effect of the urease inhibitors on the soil ureases at varying nitrogen levels

The levels of the nitrogen applied affect not only the rice growth but also the fate of it. At the levels ranging from 50 mg N (N_1) to 150 mg N (N_3) per kilogram of soil, the grain yield, the shoot biomass, the total uptake of N by rice and the ratio of grain N over total N increased to 37.1, 69.8, 945 mg per pot and 69% from 18.2, 41.7, 494 mg per pot and 57% (see Table 4). However, the excessive use of nitrogen decreased the above measurements. This occurred in the treatment applied at the rate of 200 mg N per kilogram of soil (N_4). Also, the N uptake by rice from the fertilizer applied increased as the N level, e.g., from 115 mg at N_1 to 337 mg at N_4.

Table 4 Effect of urease inhibitors on agronomic chacracteristics and N absorption of rice plants at diffenect level of urea

Treatment	Urease inhibitor	Grain weight g·pot^{-1}	Shoot biomass g·pot^{-1}	Total N uptade mg·pot^{-1}	Grain N/total N	Uptake of ferfilizer N mg·pot^{-1}
	PPD	12.4	36.0	427	0.46	115
N_1	NBPT	12.0	34.4	443	0.46	114
	HQ	24.3	48.3	537	0.68	116
	UO	24.0	48.2	567	0.67	116
	PPD	34.7	63.3	780	0.69	238
N_2	NBPT	30.6	58.4	707	0.66	227
	HQ	29.6	55.2	620	0.67	185
	UO	26.6	52.0	594	0.63	166
	PPD	41.3	73.9	950	0.72	319
N_3	NBPT	36.8	67.7	1049	0.69	324
	HQ	36.3	69.6	963	0.68	256
	UO	34.1	67.8	817	0.65	239
	PPD	21.9	50.7	866	0.55	384
N_4	NBPT	19.6	44.6	923	0.41	390
	HQ	8.6	24.8	621	0.32	305
	UO	3.2	15.6	340	0.23	269

Based on the the fate of the ^{15}N-urea applied (see Table 5), the ^{15}N utilization by rice inversely correlated to the nitrogen levels used, decreasing to 42.1% at N_1 from 57.6% at N_4. The ^{15}N loss correlated to the nitrogen level, increasing to 39.0% at N_4 from 20.7% at N_1. The values of the ^{15}N residue were around 20% at the four nitrogen levels used.

The use of the urease inhibitors had a conspicuous effect on the rice growth. At the low nitrogen level, the urease inhibitors decreased the uptake of N by rice due to the decrease of N supply from soil (see Table 4), slowing the rice growth. The increase of the N supply led to the disappearance of the negative effect from the urease inhibitors. Indeed, the urease inhibitors at appropriate levels of N supply enhanced the uptake of total N and fertilizer N by rice, the shoot biomass, and the grain yield. Particularly, at the high level of N supply (N_4), the urease inhibitors relieved the toxic effect from the excessive nitrogen.

The urease inhibitors also affected the fate of the nitrogen applied at different N levels. The fate of the low-level nitrogen (N_1) was nearly the same in the treatments with different urease inhibitors. As the level of the N supply increased, the urease inhibitors apparently increased the utilization of the ^{15}N fertilizer (43.2% for UO, 46.3% for HQ, 54.1% for NBPT, 54.6% for PPD) and decreased its loss (38.6% for UO, 24.3% for PPD, 25.1% for NBPT, 35.2% for HQ) (see Table 5).

Table 5 Effect of urease inhibitors on ^{15}N-urea fate at diffenent level of urea

Treatment	Ureas inhibitor	^{15}N utilization efficiency/%	^{15}N residue/%	^{15}N lose/%
	PPD	57.6	22.5	19.9
N_1	NBPT	56.9	23.5	19.6
	HQ	58.2	20.5	21.3
	UO	57.7	20.5	21.8
	PPD	59.5	21.5	19.0
N_2	NBPT	56.7	20.6	22.7
	HQ	46.1	17.0	36.9
	UO	41.4	17.1	41.5
	PPD	53.2	20.5	26.3
N_3	NBPT	54.1	19.5	26.4
	HQ	42.7	18.2	39.1
	UO	39.9	17.5	42.6
	PPD	48.0	20.0	32.0
N_4	NBPT	48.7	19.5	31.8
	HQ	38.1	18.3	43.6
	UO	33.6	18.0	48.4

Based on the data above, the urease inhibitors at the reasonable levels of nitrogen fertilizer may take an important part in promoting rice growth, enhancement of its utilization, reduction of its loss, and increase of grain yield. They may also alleviate, to some degree, the environmental pollution by ammonia. With these in consideration, the PPD and NBPT are recommended for application though they acted poorly at the low level of nitrogen supply.

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