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Ammonia volatilization losses and ^{15}N balance from urea applied to rice on a paddy soil

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Abstract: Ammonia volatilization loss and ^{15}N balance were studied in a rice field at three different stages after urea application in Taihu Lake area with a micrometeorological technique. Factors such as climate and the NH_4^+-N concentration in the field floodwater affecting ammonia loss were also investigated. Results show that the ammonia loss by volatilization accounted for 18.6%—38.7% of urea applied at different stages, the greatest loss took place when urea was applied at the tillering stage, the smallest at the ear bearing stage, and the intermediate loss at the basal stage. The greatest loss took place within 7 d following the fertilizer application. Ammonia volatilization losses at three fertilization stages were significantly correlated with the ammonium concentration in the field floodwater after the fertilizer was applied. ^{15}N balance experiment indicated that the use efficiency of urea by rice plants ranged between 24.4% and 28.1%. At the early stage of rice growth, the fertilizer nitrogen use efficiency was rather low, only about 12%. The total amount of nitrogen lost from different fertilization stages in the rice field was 44.1%—54.4%, and the ammonia volatilization loss was 25.4%—33.3%. Reducing ammonia loss is an important treatment for improving N use efficiency.

Keywords: ammonia volatilization; urea; ^{15}N balance; rice; influence factors, Taihu region

Introduction

The loss of ammonia via volatilization constitutes a very large proportion in the nitrogen fertilizer loss from the rice field. Previous studies showed that the ammonia volatilization loss in the case of nitrogen fertilizer topdressing accounted for 10%—60% of the total nitrogen fertilizer applied (Fillery and Datta, 1986). The research in China indicated that the ammonia volatilization loss in the rice field system makes up 9%—40% of the total nitrogen fertilizer applied (Cai and Zhu, 1995). In 1990, the global ammonia volatilization loss was about 54 TgN/a NH_3-N, of which was 9 Tg N/a NH_3-N from ammonia volatilization of chemical fertilizer (Oliver *et al.*, 1998). In the agriculture ecosystem of China, the NH_3-N that released into environment was about 1.80 Tg in 1990, which consisted of 11% of chemical N fertilizer applied (Xing and Zhu, 2000), while it increased to 2.71 Tg N in 1995. Ammonia volatilization from paddy soil was higher than upland, which were 18% and 9% respectively (Xing and Zhu, 2000). Therefore, studying ammonia volatilization from paddy soil and reasonable fertilization practices are of great significance for reducing the adverse effect of fertilizer application on the environment.

The major factors affecting the ammonia volatilization loss include climatic conditions (e.g. temperature, sun light intensity and wind speed), soil properties, the chemical nature of the field surface water, the amount and method of fertilizer application, the crop covering. The amount of ammonia volatilization fluctuates greatly with the change of soil and climatic condition (Cai, 1992). The balance of ammonia steam press P_{NH3} and the air floating had an obvious influence on the rate of ammonia volatilization (Larsen and Gunary, 1962). Urea is an essential type of nitrogen fertilizer used in the rice production in China, but its use efficiency was about 30% , most of which was lost by ammonia volatilization(Zhu, 1992). In China, Taihu Lake region is an area where high yields of rice are achieved and high rates of nitrogen fertilizer are used. However, so far little has been done on a systematic study on the process and the quantity of ammonia volatilization from applied nitrogen fertilizers in rice production and its importance in total nitrogen loss.

The objectives of this study were to elucidate the effect of quantity and process of urea on ammonia volatilization and to evaluate its importance in total nitrogen loss for improving N use efficiency in the rice production of Taihu Lake.

1 Materials and methods

1.1 Ammonia volatilization measurement

The study was carried out on a farmer's rice field adjacent to the Changshu Agroecological Experimental Station, Chinese Academy of Sciences (Changshu County, Jiangsu Province, China) in 2002. The soil was a paddy soil (Gleyi-stagnic Anthrosol according to Soil Survey Staff (1996)). The surface layer of the soil (0—20 cm) had a pH of 7.15(soil: water ratio, 1:2.5), an organic matter content of 44.6 g/kg, a total N content of 2.73 g/kg, an available P (Olsen test) of 6.76 mg/kg, and an available K of 97.5 mg/kg.

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In this study, there were three experiments, including the basal fertilizer stage, tillering fertilizer stage and the ear bearing fertilizer stage. To measure ammonia volatilization, three treatments were established in the test field: 2 circular plots, each 25 m in diameter with 50 m between the plots, with a low N level of 135 kgN/hm^2 (LN) and a high N level of 270 kgN/hm^2(HN) as urea, respectively, and a control plot at 50 m distance, upwind of the treated circular plots which did not receive any N fertilizer during the experimental period. For measurement of NH_4-N in surface water, the sampling plots were also established in the same field, 50 m distant from the 2 circular plots used to determine ammonia volatilization so as not to disturb them. The sampling plots were treated with the same rate and method of fertilizer application as the 2 circular plots and control plot. Here there were also three treatments (control, low nitrogen, and high nitrogen) with three replicates, each plot being 60 m^2.

Rice seedlings were transplanted on June 22, 2002. According to the local farming practices, urea was surface-broadcasted at three stages: 30% at transplanting on June 22, 40% at tillering on July 20, and 30% at ear bearing stage on August 20. The same proportion of P (60 kg/hm^2 P_2O_5) and K (60 kg/hm^2 K_2O) fertilizers were applied the three stages as for urea in all treatments including the control. Ammonia volatilization measurement started immediately after urea application and stopped when the NH_3 flux was negligible with 24 h sampling intervals, by the NH_3 sampler method, based on a micrometeorological mass balance technique (Denmead *et al.*, 1977; Denmead, 1983; Leuning *et al.*, 1985; Cai *et al.*, 1998). Samplers were mounted at 5 heights, 0.4, 0.8, 1.2, 1.6, and 2.0 m above the soil surface, at the center of each fertilized circular plot and in the control plot. The mass of NH_3 collected in each sampler by oxalic acid coating was measured with a colorimetric method after elution in deionized water. The net mean horizontal flux density, $\overline{uc}$ (product of mean wind speed(u) and net mean concentration of ammonia(c)), during sampling interval t was calculated as:

$$\overline{uc} = M/(At) \quad (1)$$

where M is the difference between the mass of collected NH_3 of the N treatment and that of the control, and A is the effective cross-sectional area of the sample (2.42 $\times 10^{-5}$ m^2). The net vertical flux density, F, of NH_3 was given by:

$$F = 1/x \int_0^z \overline{uc}\,dz \quad (2)$$

where x is the fetch or the distance travelled by the wind over the fertilized area (*i.e.*, the radius of the circle, 12.5 m), and z is the height of the air layer affected by NH_3 emissions. Surface water samples were taken randomly from each plot straight after NH_3 volatilization measurement. After filtering, NH_4-N was measured with the colorimetric method(Lu, 1999).

1.2 Design of the micro-plot experiment

Another plot of land was selected on the periphery of the round area where ammonia volatilization was being determined, and a micro-plot experiment was set up in 3 treatments of control(CK), low N (LN) and high N (HN). Each treatment had 4 replicates. The CK was designed with 4 cylinders, while LN with 12 cylinders, and HN with 12 cylinders. A cylinder has a diameter of 30 cm, and a height of 60 cm. There was an interval of 1.5 m between cylinders. The cylinders were lined up in 7 rows and driven down into the soil at a depth of 45 cm. The urea tested had a ^{15}N abundance of 5%. Hole transplanting was done, with 3 holes in one cylinder and 3 plants in one hole. After measurements of ammonia volatilization at transplanting and tillering, 4 cylinders were taken out of each of the micro-plots treated with LN and HN, respectively. The other cylinders were taken out of the CK and of the micro-plots treated with LN and HN at the final harvest.

1.2.1 Sample collection and analysis

The soil used in the micro-plot cylinder was sampled separately from four horizons: 0—20, 20—40, 40—60, and 60—80 cm. Soil samples were air-dried, ground through a 100-mesh, and prepared for analyzing total N and ^{15}N. Plants were sampled, washed clean and separated one from another. The plants were divided into 3 parts: roots, stem and grain. They were placed in an oven at 105℃ for a 30-min degreening, and dried at 65℃ till a constant weight. Then they were ground and prepared for analytical use.

1.2.2 Methods for analyses of soil and plant nutrients referred to the literature(Lu, 1999)

Soil and plant total N was determined by the semi-micro Kjeldal digestion method. ^{15}N was determined by an isotope mass-spectrometer.

1.2.3 Apparent nitrification-denitrification loss calculation

The apparent nitrification-denitrification loss(%) = the total fertilizer N loss by ^{15}N technique (%) - total ammonia volatilization loss(%)

The statistical analysis was carried out by SPSS V10.0.

2 Results and discussion

2.1 Dynamic changes of ammonia volatilization flux density

The dynamic changes of ammonia volatilization at different fertilization stages are shown in Fig.1. The peak of the ammonia volatilization appeared on the 24—48 h following the application of nitrogen fertilizer. The highest flux of ammonia volatilization occurred at the tillering stage(whose maximum flux in treatments HN and LN was 11.17 and 6.79 kgN/(hm²·d), respectively (Fig.1b)), the lowest flux at the ear bearing stage (whose maximum flux in HN and LN was 5.52 and 1.72 kgN/(hm²·d),respectively(Fig. 1c)), and the intermediate flux density at the basal fertilizer stage (whose maximum flux density in HN and LN was 7.49 and 3.01 kgN/(hm²·d),respectively(Fig. 1a)). Among these, the maximum ammonia volatilization flux at the high N rate was 1.65—3.21 times that obtained at the low N rate at the same stage.

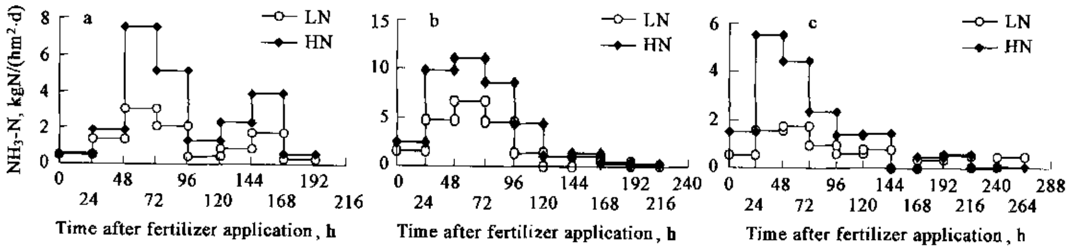

Fig.1 Flux density of NH_3 volitilization from the basal fertilizer(a), tillering fertilizer(b) and ear bearing fertilizer(c)

It can be seen from the above figures that the first 168 h following the fertilizer application was a critical period in which the ammonium nitrogen dehydrated from urea was being lost by ammonia volatilization. The amount of ammonia volatilized during the 168 h accounted for 80.7%—94.3% of the total ammonia volatilized correspondingly at each of the fertilization stages, with the greatest amount and proportion of the volatilized ammonia at the tillering fertilizer stage and the smallest at the basal fertilizer stage. It is mainly the different climatic conditions at different fertilization stages that brought about the variation in ammonia volatilization.

2.2 Ammonia volatilization loss at different stages

The quantity of ammonia lost by volatilization increased as the rate of fertilizer application increased (Table 1). At the stage of basal fertilizer, the ammonia volatilization loss in Treatments LN and HN was 10.28 and 23.08 kgN/hm², constituting 25.4% and 28.5% respectively of the fertilizer applied. At the tillering stage, it was 20.91 and 39.79 kgN/hm², making 38.7% and 36.8% respectively of the fertilizer applied, whereas at the ear bearing stage, it was 7.53 and 17.89 kgN/hm², occupying 18.6% and 22.1%, respectively, of the fertilizer added. On the whole, in the rice field production system the ammonia volatilization loss commonly accounted for 18.6%—38.7% of the fertilizer applied, which is much higher than the value of 9% obtained in the study using urea on a Huangni soil(Cai *et al.*, 1985). The major reason for this is the big difference in the pH value between the two experimental sites. Soil pH was one of the important factors affecting ammonia volatilization in the rice field. The Huangni soil has a pH of 5.4, while the soil studied in this experiment has a pH of 7.07. Judging from the different fertilization stages for rice growth, the magnitude of ammonia volatilization loss in this experiment can be expressed by the following descending order: tillering > basal > ear bearing stage.

Table 1 NH_3 volatilization losses during the whole period of rice growth

Treatment	Total fertilizer applied, kgN/hm²	Amount of ammonia volatilized			
		At basal fertilizing, kgN/hm²	At tillering fertilizing, kgN/hm²	At ear bearing fertilizing, kgN/hm²	Total, kgN/hm²
LN	135	10.28 (25.4)	20.91 (38.7)	7.53 (18.6)	38.72 (28.7)
HN	270	23.08 (28.5)	39.79 (36.8)	17.89 (22.1)	80.76 (29.9)

Notes: The numerical value in parentheses denotes ammonia loss percentage of the amount of the N fertilizer applied at transplanting, tillering, ear bearing stages and the total

2.3 Effect of NH_4^+-N concentration of floodwater on ammonia volatilization in the rice field

Fig.2 shows the dynamic changes of the NH_4^+-N concentration in the rice field floodwater after applying the basal fertilizer, tillering fertilizer and ear bearing fertilizer, respectively. By comparing Fig.2 correspondingly with Fig.1, we can see a basic agreement in the change trend between the NH_4^+-N concentration in floodwater and the ammonia flux density, and this tallies with many researche s ' conclusion that the NH_4^+-N concentration in the field floodwater is one of the important factors determining the amount of ammonia volatilized from the rice field (Fillery and Dattaa, 1986; Cai and Zhu, 1985; Cai *et al.*, 1992; Freney *et al.*, 1985).

After fertilizer application, the NH_4^+-N concentration in the floodwater increased quickly and soon reached the peak value within 24—48 h, and afterwards it began to fall. As the temperature was rather low when the basal fertilizer was applied, it was relatively late for the concentration to reach the peak value (Fig.2). The maximum concentration of the floodwater NH_4^+-N in treatments LN and HN at the basal fertilizer stage was 7.43 and 11.26 mgN/L(Fig. 2a), whereas at the tillering stage it was 25.04 and 46.62 mgN/L (Fig.2 b)), and at the ear bearing stage it was 6.13 and 8.21 mgN/L (Fig. 2c)), respectively.

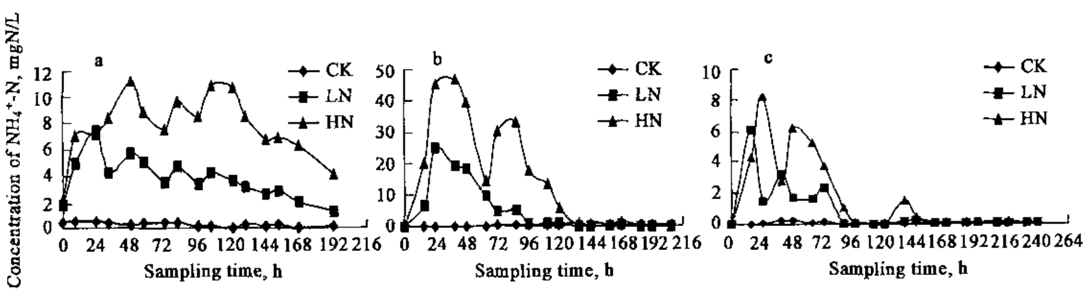

Fig.2 Change of NH_4^+-N in floodwater after applying the basal fertilizer(a), tillering fertilizer(b) and ear bearing fertilizer(c)
CK: control; LN: low N level; HN: high N level

Although the application rate at the tillering stage was 1.3 times that of the ear bearing fertilizer and basal fertilizer, its highest NH_4^+-N concentration was 4.1 (LN) and 5.7 (HN) times that of the ear bearing stage, and 3.4 (LN) and 4.1 (HN) times that of the basal fertilizer.

Significance test shows that at the basal fertilizer stage the NH_4^+-N concentration among different treatments reached a highly significant difference ($p<0.01$); at the tillering stage the concentration between a low rate of N and CK reached a significant difference ($p<0.05$), and between a high rate of N and CK reached a highly significant difference($p<0.01$); at the ear bearing stage the concentration between HN and control reached a highly significant difference ($p<0.01$), and between HN and LN reached a significant difference($p<0.05$).

2.4 Effect of climatic conditions on ammonia volatilization

By studying the relations between the ammonia volatilization flux and climatic conditions such as: temperature, sunlight intensity, wind speed and rainfall, we found that ammonia volatilization is affected more or less by different climatic conditions at different stages of rice growth.

Cai *et al.*(1985) considered that, after application of urea in the rice field, the volatilization of ammonia from the added nitrogen fertilizer depended mainly on weather conditions. When it was cloudy or rainy, ammonia volatilized rather weakly. Our present experiment has also confirmed this point. When basal fertilizer was applied to the rice plant, it was mostly cloudy and drizzly. The sunlight was weak, with a maximum daily rainfall of up to 45.2 mm but the average daily sun radiation of only 12.94 MJ/m^2.

When the ammonia volatilization was determined at the tillering stage, the temperature was comparatively high, with the highest up to 40.9℃ and the average ranging between 26.7—31.7℃. It was sunshine, with the average daily radiation of 17.96 MJ/m^2. The rainfall was relatively low. It can thus be seen that in the period of various conditions, such as the high temperature, strong sunlight, low rainfall, etc., enhanced the urease activity, stimulated the urea to break down quickly and give off a large amount of ammonium nitrogen, thus accelerating the loss by ammonia volatilization.

At the earing stage the temperature usually ranged between 26.7 and 30.4℃, which was slightly lower than at the tillering fertilizer stage. The sunlight was fairly strong, with the average daily radiation of 19.74 MJ/m^2. The cumulative rainfall was 29.1 mm, which was higher comparing with the tiller fertilizer stage, but lower comparing with the basal fertilizer stage. At the ear bearing stage, among the various meteorological conditions, the sunlight intensity and air temperature affected ammonia volatilization most obviously, their correlation R^2 value being 0.2278 ($p=0.05$, $n=24$) and 0.477($p=0.01$, $n=24$), respectively.

2.5 Fertilizer N balance at different fertilization stages

Table 2 presents the nitrogen balance status at different fertilization stages for rice plant. It can be seen from the table that although the absorption and assimilation of nitrogen fertilizer by rice plants enhanced gradually as the plant growth went on, yet on the whole, the efficiency of nitrogen fertilizer use by rice plants was still low, with the highest value of only 28.1%. The fertilizer N use efficiency of urea applied at the three stages of "basal fertilizer", "basal fertilizer+tillering fertilizer", and "basal fertilizer+ tillering fertilizer+ear bearing fertilizer" was 11.9%—13.6%, 20.6%—23.1% and 24.4%—28.1%, respectively. Statistical analyses show that in the same fertilization stage the rice plant had no significant difference in using nitrogen fertilizer under different treatments; at different fertilization stages, however, the fertilizer N use efficiency by rice plant reached a significance level.

It can also be seen from Table 2 that most of the fertilizer nitrogen applied before the ear bearing stage was lost, some of it remained in the soil, so the crop plants only absorbed the smallest amount of the fertilizer nitrogen. With the needs of crop growth, the fertilizer nitrogen absorbed by rice plant transferred gradually to the stem and grain.

2.6 Loss of fertilizer nitrogen

Results obtained from our present study(Table 3)

Table 2 Nitrogen balance at different fertilization stages for rice plant, %

Fate of N	Basal manure		Basal manure+ tiller fertilizer		Basal manure+ tiller fertilizer+ earing fertilizer	
	LN	HN	LN	HN	LN	HN
Stem ^{15}N	10.7	10.1	18.7	21.7	10.2	12.3
Root ^{15}N	2.9	1.8	1.9	1.4	1.6	1.3
Grain ^{15}N	/	/	/	/	12.6	14.5
Soil ^{15}N	42.3	33.7	29.8	27.9	26.2	20.3
Soil+Plant ^{15}N	55.9	45.6	50.4	51.0	50.6	48.4
Fertilizer N use efficiency of rice	13.6	11.9	20.6	23.1	24.4	28.1
Loss from fertilizer	44.1	54.4	49.6	49.0	49.4	51.6

Table 3 Loss of chemical fertilizer nitrogen in the rice field, %

Treatment	Basal manure		Basal manure+ tiller fertilizer		Basal manure+ tiller fertilizer+ earing fertilizer	
	LN	HN	LN	HN	LN	HN
Total N fertilizer loss	44.1	54.4	49.6	49.0	49.4	51.6
Ammonia loss	25.4	28.5	33.0	33.3	28.7	29.9
Apparent nitrification-denitrification loss	18.7	25.9	16.6	15.7	20.7	21.7

shows that the total quantity of nitrogen loss from therice field ranged between 49 % and 54.4%, and that ammonia volatilization was an important way of nitrogen loss, by which 25.4%—33.3% of the nitrogen applied was lost. But the apparent nitrification-denitrification loss obtained through calculation also constituted a fairly large proportion; therefore, this way of nitrogen loss should not be overlooked.

3 Conclusions

In the rice field production system studied in this experiment, the ammonia lost by volatilization accounted for 18.6%—38.7% of the nitrogen fertilizer applied at each of the fertilization stages. The greatest amount or proportion of ammonia was volatilized at the tillering fertilizer stage. Climatic conditions, especially the temperature, sunlight intensity and rainfall, had more significant effects on ammonia volatilization during different periods of rice growth. The magnitude and change of the NH_4^+-N concentration in the field floodwater directly determined the magnitude of the ammonia volatilization. The order of the magnitude of ammonia loss by volatilization at the three stages of fertilisation is: the tillering stage > the basal stage > the ear bearing stage. Based on the ^{15}N balance experiment, the use efficiency of chemical nitrogen fertilizer in rice plants ranged between 24.4% and 28.1%. At the early stage of rice growth, the fertilizer nitrogen use efficiency was rather low, only about 12%. The total amount of nitrogen lost from the rice field was 44.1%—54.4%, and the ammonia volatilization loss was 25.4%—33.3%. Ammonia volatilization was a main way of nitrogen loss from the fertilizer. Therefore, it is possible, according to the characteristics of ammonia volatilization at different fertilization stages, to decrease the amount of ammonia volatilized from the rice field by controlling the application rate of nitrogen fertilizer at the highly volatilizing stage and by retarding the rate of urea hydrolysis.

References:

Cai G X, Zhu Z L, Zhu Z W *et al.*, 1985. Study on nitrogen loss of ammonium bicarbonate and urea from paddy field [J]. Soils, 17 (5): 225—229.

Cai G X, 1992. Ammonia volatilization [M]. In: Nitrogen in soils of China (Zhu Z L, Wen Q X, ed.). Nanjing: Jiangsu Science and Technique Press. 171—196.

Cai G X, Zhu Z L, 1995. Evaluation of gaseous nitrogen losses from fertilizers applied to flooded rice fields [J]. Acta Pedologica Sinica, 32(Supp.): 128—135.

Cai G X, Fan X H, Yang Z *et al.*, 1998. Gaseous loss of nitrogen from fertilizers applied to wheat on a calcareous soil in North China Plain[J]. Pedosphere, 8: 45—52.

Denmead O T, Simpson J R, Freney J R, 1977. A direct field measurement of ammonia emission after injection of anhydrous ammonia [J]. Soil Science Society of America Journal, 41: 1001—1004.

Denmead O T, 1983. Micrometeorological methods for measuring gaseous losses of nitrogen in the field [M]. In: Gaseous loss of nitrogen from plant-soil systems(Freney J. R., Simpson J. R., ed.). The Hague: Martinus Nijhoff/Dr W. Junk Publishers. 133—157.

Fillery R P, De Datta S K, 1986. Ammonia volatilization from nitrogen fertilizer as a N loss mechanism in flooded rice fields [J]. Fert Res, 9: 78—98.

Freney J R, Leuning R, Simpson J R *et al.*, 1985. Estimating ammonia volatilization from flooded rice fields by simplified techniques[J]. Soil Sci Soc Am J, 49: 1049—1054.

Larsen S, Gunary D, 1962. Ammonia loss from ammoniac fertilizers applied to calcareous soils[J]. J Sci Food Agric, 13: 566—572.

Leuning R, Denmead O T, Simpson J R, 1985. A sampler for measuring atmospheric ammonia flux [J]. Atmospheric Environment, 19: 1117—1124.

Lu R K, 1999. Soil Agricultural chemical analytical methods [M]. Beijing: Chinese Agricultural Science and Technology Press. 146—165.

Oliver J G J, Bouwman A F, Hoek K W V, 1998. Global air emission inventories for anthropogenic sources of NOx, NH_3 and N_2O in 1990[J]. Environmental Pollution, 102(Supp.1): 135—148.

Soil Survey Staff, 1996. Keys to soil taxonomy [Z]. United States Department of Agriculture: Washington, DC.

Xing G X, Zhu Z L, 2000. An assessment of N loss agricultural fields to the environment in China [J]. Nutrient Cycling in Agroecosystems, 57: 67—73.

Zhu Z L, 1992. Management in nitrogen and fate of fertilizer nitrogen in agroecologic system [M]. Nitrogen in soils of China (Zhu Z. L., Wen Q. X., ed.). Nanjing: Jiangsu Science and Technique Press. 213—249.

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