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Simulating Ammonia Volatilization from Applications of Different Urea Applied in Rice Field by WNMM

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ABSTRACT Ammonia (NH_3) volatilization from a silty clay loam paddy soil applied with non, straight urea, and coated urea, respectively, under transplanting in Milyang, Korea from 2002 and 2003 was simulated by a Water and Nitrogen Management Model (WNMM). Based on the data from the in-situ measurements, NH_3 volatilization during the rice growth was 6.04% and 1.46% of the applied nitrogen (N) from straight urea and coated urea, respectively. The bulk aerodynamic approach in WNMM satisfactorily predicted the difference in NH_3 loss during the given rice growing seasons from the two urea fertilizers. R^2 for the correlation between the predicted and observed NH_3 loss during the calibration year (2002) was 0.53 less than 0.68 of the application year (2003). This difference could be due to the weather condition such as heavy rainfall and temperature during the calibration year.

Keywords : ammonia volatilization, paddy field, coated urea, simulation

Slow-releasing fertilizer saved 20% of N fertilization compared to urea in direct-sown rice in Korea (Kim *et al.*, 1996) and the main reason considered as diminished ammonia volatilization. Ammonia volatilization can be a major form of gaseous N loss from flooded paddy soils and causes low N use efficiency. It varies from 10 to 50% of the N amount applied (Fillery and Vlek, 1986). It is one of the reasons of the large NH_3 loss from urea and ammonium based fertilizers (Vlek and Craswell, 1979; Fenn and Hossner, 1985; Whitehead and Raistrick, 1993; Lee *et al.*, 1999) Jayaweera and Mikkelsen (1990) found that ammonia volatilization in the paddy field is influenced by five major factors i.e. ammonium concentration, pH, temperature, depth of floodwater and wind speed.

Ammonium-N in the soil is lost as ammonia under high pH and makes an equilibrium with ammonium in soil solution (Fenn and Hossner, 1985). The effect of temperature on ammonia volatilization may also be related to nitrification of NH_4^+. Ammonia volatilization can be reduced if the conditions are more favorable to nitrification because of decreasing the availability of NH_4^+ and pH in the soil (Sommer and Ersboll, 1996).

$$NH_4^+ + OH^- \rightleftharpoons H_2O + NH_3 \quad (1)$$

Ammonia volatilization increases with the increase in water pH (equation 1) and is also affected by soil properties such as texture, urease activity, moisture, wind speed, and temperature, nitrification inhibitor and acidic materials (Vlek and Craswell, 1979).

To predict N dynamics in agroecosystems, soil N simulation models are quantitative tools based on scientific knowledge that can evaluate the effects of climatic, edaphic, hydrologic and agronomic factors. A number of models are used to simulate water dynamics, crop growth and C/N turnovers, these include DAISY (Hansen *et al.*, 1990), DNDC (Li *et al.*, 1992), EPIC (Williams, 1995), CENTURY (Parton *et al.*, 1996), DAYCENT (Parton *et al.*, 1996) and WNMM (Li. 2002). Most of the models simulate modelling soil N minera-

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lization, immobilization, nitrification, denitrification, ammonia volatilization, N leaching and plant uptake.

A study was carried out to investigate ammonia volatilization from non, straight urea and coated urea treated Korean paddy soil under transplanting rice culture in 2002 and 2003. The simulation of ammonia volatilization by WNMM was also exercised in this paper.

MATERIALS AND METHODS

Treatment and rice transplanting

Latex coated urea, a controlled release fertilizer which is a form urea blended with several types of latex coatings for different release periods (Shoji and Gandeza, 1992). N release patterns of coated urea only depend on only temperature variation. The N releasing pattern of a coated urea blended with 3 types is shown in Fig. 1.

Three treatments of coated urea (N:40%), non and straight urea (N:46%) were setup in a transplanted rice field for 2 years (2002 and 2003). In straight urea treatment, 55 kg N ha^{-1} of urea with mixed soil was applied as basal application prior to transplanting, and 33, 22 kg N ha^{-1} was top dressed at 5 leaf and panicle formation, respectively. In coated urea treatment, 110 kg N ha^{-1} of coated urea blended with straight urea, 40-day type, 70-day and 100-day (50:20:20:10) was applied as whole basal application with mixed soil prior to transplanting. Rice (*Oryza sativa* L.) was transplanted on 1st June 2002, and 8th June 2003, and harvested on 5th October 2002 and 7th October 2003, respectively.

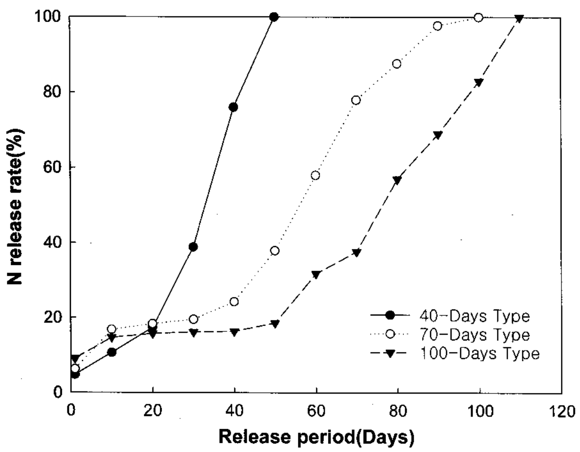

Fig. 1. N release pattern of coated urea blended with 40, 70 and 100-day types in 30℃ water.

Measurement of ammonia volatilization

To trap ammonia volatilized from the treatment plots, a system of semi open static ammonia absorbers was used in the field (Nommik 1973). The acryl cylinder was installed to collect ammonia volatilized from the surface water on the paddy soil. The base of acryl cylinder that 40 cm high and 20 cm in diameter was inserted 5 cm into the paddy soil. Two sponges of polyurethane plastic foam which had a diameter of 200 mm and thickness of 20 mm were used to absorb ammonia. Before using the sponges were leached alternately with 1 M H_3PO_4 and 1 M KOH solution and, finally with distilled water. The sponges were soaked in the solution containing 35 ml conc. H_3PO_4 and 50 ml glycerol per liter before installation in a cylinder. The lower ammonia absorber disc has the function to take up volatilized ammonia from the soil and the upper disc serves to hinder a contamination of the inner system with the atmospheric ammonia. After fixed periods of exposure the upper ammonia absorber sponge was removed and replaced with a new reloaded one. The excess of the solution was removed from the sponges by strong squeezing and the solution was analysed for ammonium-N by Auto analyzer 3 (BRAN LUEBBE). The sponges were collected after every 3 days for calculating ammonia volatilization rate. Meantime, pH was also measured in the surface paddy water.

Weather data

The daily weather variables maximum and minimum air temperature, solar radiation, rainfall, relative humidity and wind speed of 2002 and 2003 for the study site were collected from Korean Meteorological Administration web site.

WNMM Model

The WNMM simulates the key processes of water and N dynamics in the surface and subsurface of soils, including evapotranspiration, canopy interception, water movement, groundwater fluctuations, soil temperature, solute transport, crop growth, N cycling in soil-crop system, and agricultural management practices (crop rotation, irrigation, fertilizer application, harvest, and tillage). It runs at a daily time step at a range of scales, and was fed with lumped variables (climatic data and crop biological data) in text data format and spatial variables (soil and agricultural management) in ARC GRID ASCII format data (Li, 2002; Li *et al.*, 2005). Generally known N cycling under soil-crop system is shown in Fig. 2.

Ammonia gas is emitted into the atmosphere following the application of nitrogenous fertilizers or from surface applied animal wastes. The following bulk aerodynamic formula was used for calculating ammonia volatilization,

$$F = kuz(Co - Cz) \quad (2)$$

where F is the flux density of ammonia from the surface, k is an exchange coefficient, uz and Cz are the mean wind speed and ammonia concentration at a reference height (z), respectively, and Co is the mean ammonia gas concentration in equilibrium with the ammoniacal-N in the liquid phase (Leuning *et al.*, 1984; Freney *et al.*, 1985).

When the water is well mixed, the surface ammonia concentration equals to that in bulk water and ammonia volatilization and may be regarded as an evaporation process from surface where the concentration is Co. The coefficient k then equals to evaporation of water and can be predicted from micrometeorological theory (Sherlock *et al.*, 1995). However,

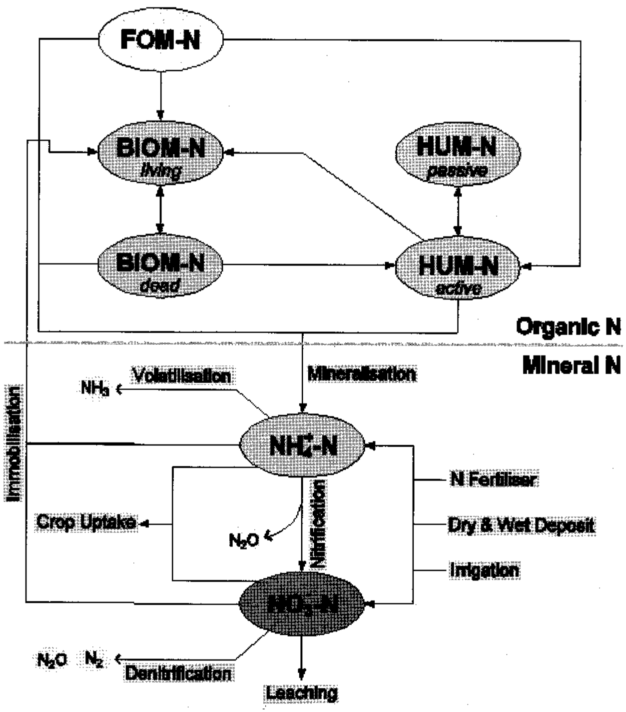

Fig. 2. Diagram of nitrogen cycling in soil-crop system.

if there is significant resistance to ammonia transfer within the liquid phase, such as there is a stable thermal stratification of water (Leuning *et al.*, 1984; Freney *et al.*, 1985), k is no longer a function of atmospheric transport processes alone and can be determined by comparison of Eq. (2) to an alternative method for measuring the NH_3 fluxes.

$$[NH_3]_{aq} = \frac{[NH_4^+ + NH_3]_{aq}}{1 + 10^{0.09018 + \frac{2729.92}{T} - pH}} \quad (3)$$

$$C_0 = [NH_3]_{aq} \cdot 10^{1.6937 - \frac{1477.7}{T}} \quad (4)$$

The ammonia concentration in equilibrium with the liquid phase at the water surface is determined by the floodwater ammonium nitrogen concentration ($[NH_4^+ + NH_3]_{aq}$), and water temperature (T, K) and pH by the equations (3) and (4) (Freney *et al.*, 1985).

RESULTS AND DISCUSSION

Water pH dynamics

The pH of surface water in straight urea immediately increased after top dressing of urea and was higher than that of coated urea and 2003 than 2002 (Fig. 3). Microbial activity in the floodwater is affected by the water pH, appears to be a major contributor to ammonia loss in the rice field (Fillery *et al.*, 1984). Sherlock *et al.* (1995) has also stated that the observed relationship between pH and ammonia flux has been consistent with the theoretical influence of pH predicted from Equation 3. A particular interest was the sharp rise in soil surface pH from 7.5 to 8.7 immediately after a light rain 5.5 days following the synthetic urine application. Coincident with this pH rise was the sharp decline in the ammoniacal-N concentration of the soil solution.

Ammonia volatilization

The amount of ammonia loss measured from paddy field in 2002 and 2003 is expressed in Table 1.

Ammonia fluxes, volatilized from urea and coated urea applied 110 kg N ha^{-1} were 6.29, 2.95 in 2002 and 11.49, 4.74 kg N ha^{-1} in 2003 respectively. One of the reasons of low ammonia loss in 2002 was rainfall during the middle of rice growth period. In transplanted rice culture, ammonia

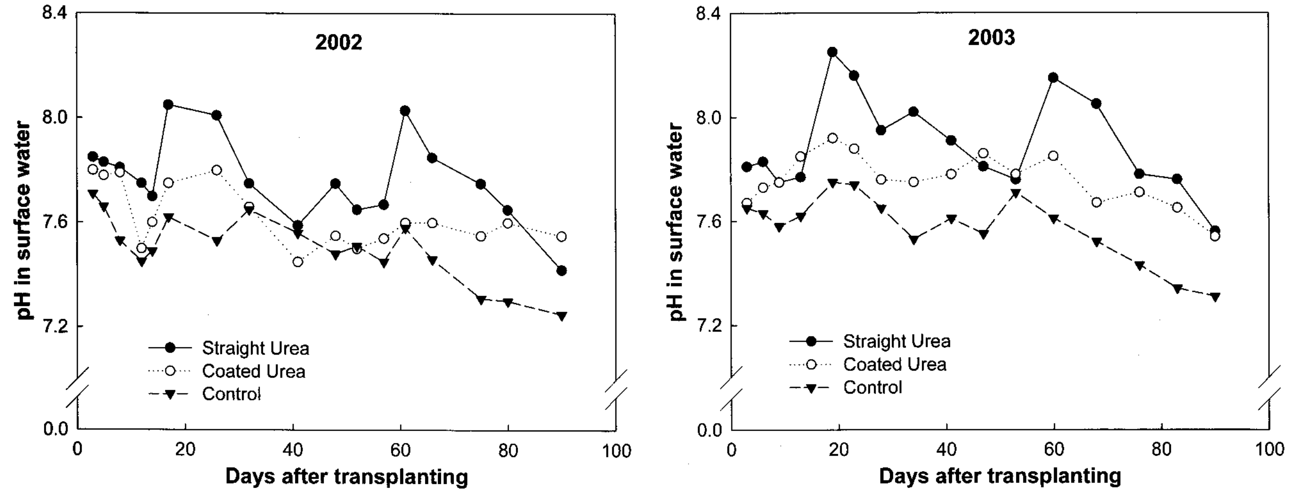

Fig. 3. Changes of pH in surface water during rice growing in paddy field.

Table 1. Ammonia losses of different treatments from a rice transplanted field in 2002 and 2003.

Treatment	N Input	2002†		2003‡	
		Measured	WNMM Prediction	Measured	WNMM Prediction
		kg N ha^{-1}			
Straight Urea	110	6.29	7.66	11.49	13.48
Coated Urea	110	2.95	4.24	4.74	5.53
Control	0	1.38	1.36	3.09	2.62

†,‡Measured period : 1st June - 7th October in 2002, 7th June - 9th October in 2003

volatilized from coated urea was decreased by 5.04 kg N ha^{-1} compared to the loss from straight urea.

WNMM simulation

Ammonia volatilization as measured by WNMM (Fig. 4 and 5) simulations and field measurements in 2002 were significantly higher than 2003. Ammonia losses simulated and measured from straight urea plot were increased by topdressings at 5 leaves and panicle formation stages of rice. On the other hand, the losses from coated urea or soil which N released slowly were continuous from early stage to middle stage of rice growth compared to straight urea. In contrast, the losses from the control treatment were very small except only at early stage after rice transplanting. During the calibration year (2002), a k value of 9.0×10^{-3} was obtained in this paddy field with 7.5 cm water depth. The k value is about 10 times higher than the depths in the trials conducted by Freney *et al.* (1985).

Ammonia losses predicted by WNMM were slightly higher than ammonia measured in urea and coated urea in two years. Especially, the losses measured at first topdressing and second topdressing from urea were higher than the predicted losses. It was presumed that there is an uncertainty in the pH change in paddy water, caused by algal growth. pH measurement once a day may not account for the average variation in water pH. Ammonia losses were increased with the increase in urease activity caused by the development of algae in the paddy field (Savent and Datta, 1982). There was some variation on ammonia loss caused by different weather conditions in 2002 and 2003. Ammonia losses in 2003 were higher than in 2002 because of heavy rainfalls during the middle of rice growth period in 2002. Ammonia volatilization is inversely related to water depth in surface water in rice paddy field (Jayaweera and Mikkelson, 1990).

Comparison of micrometeorological and semi static techniques

Few comparisons of chamber and micrometeorological

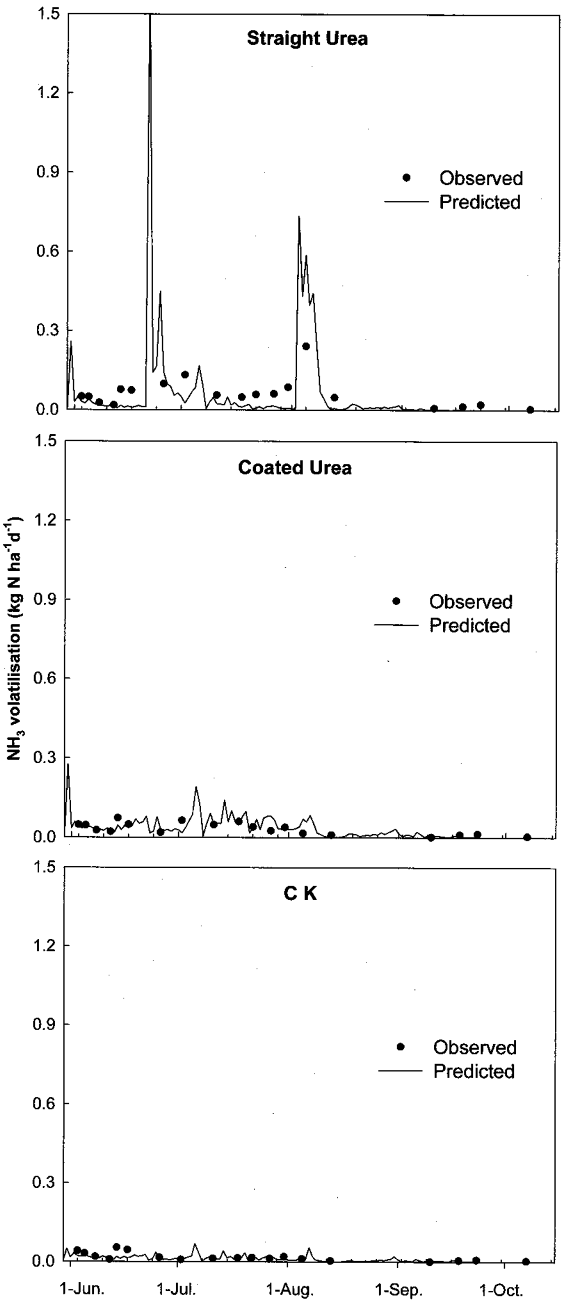

Fig. 4. Comparison of simulating ammonia and measured ammonia under different fertilizer treatment in transplanting rice culture in 2002.

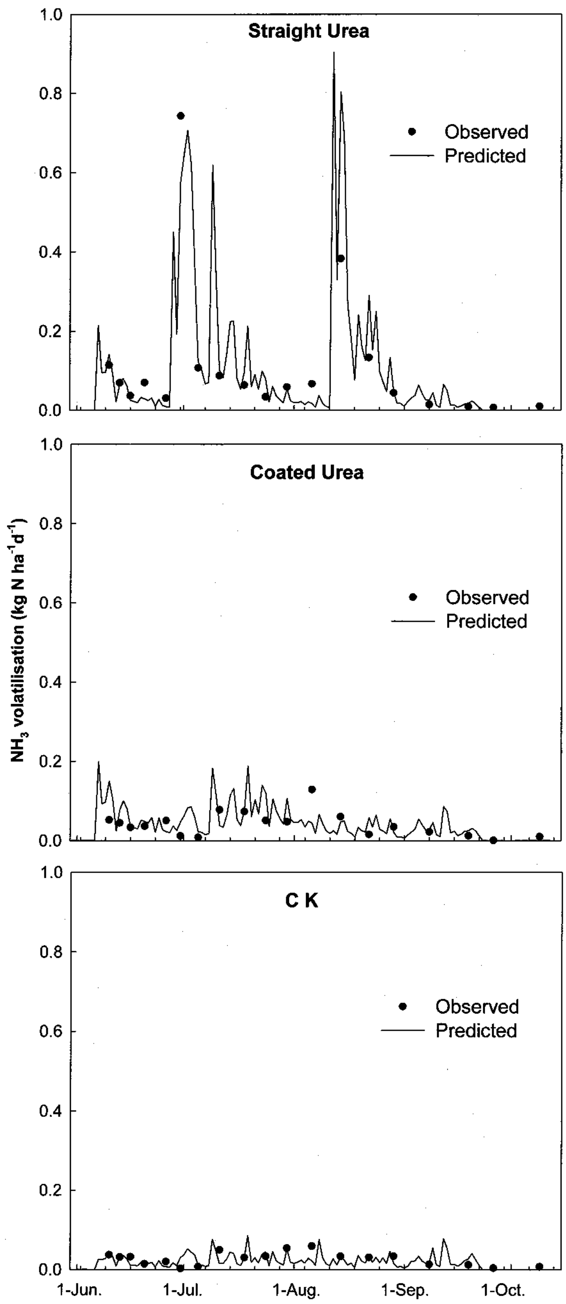

Fig. 5. Comparison of simulating ammonia and measured ammonia under different fertilizer treatment in transplanting rice culture in 2003.

methods have been undertaked in the past. Ammonia losses measured using chamber and micrometeorological techniques were compared over a 2 h period (Patricia Laville *et al.*, 1999). For the micrometeorological methods, the fluxes ranged from 20 to 400 ng N-N_2O m^2 S^{-1} and from 25 to 275 ng N-N_2O m^2 S^{-1} for chamber method. The average relative variations in the loss measured by these two methods were very similar. Although it is not a free air flow chamber system, semi open static method used this experiment may be considered as similar to micrometeorological method for measuring ammonia loss. Black *et al.* (1985) has also found that ammonia volatilization measured by enclosure system

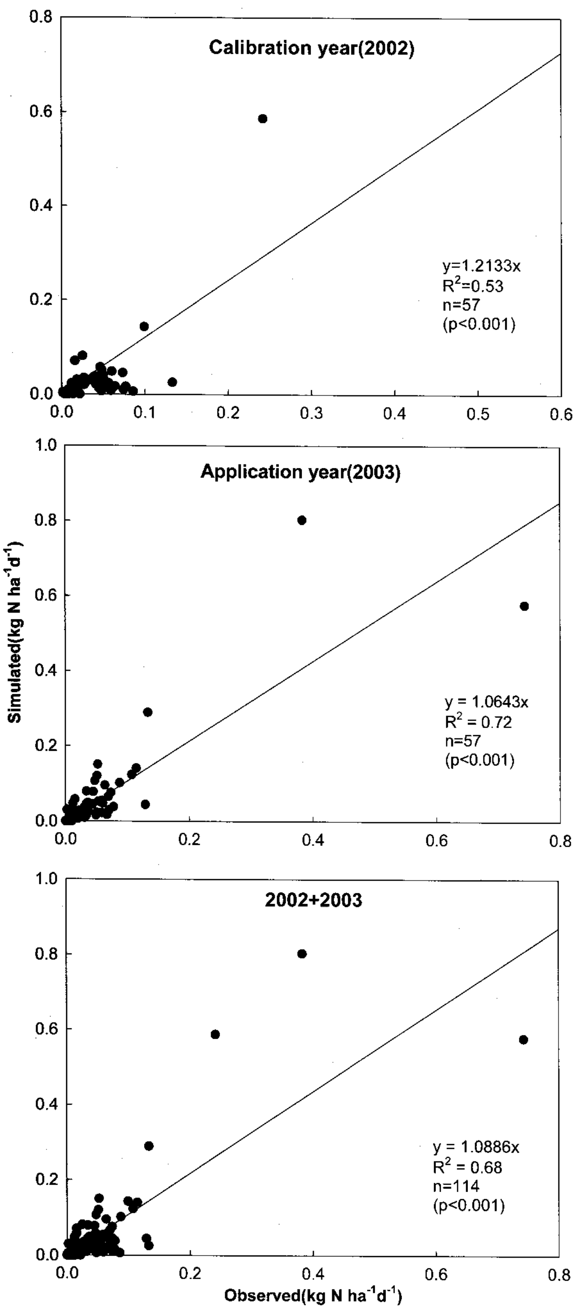

Fig. 6. The relationship between observed and simulated fluxes of ammonia volatilized from rice paddy field in 2002 and 2003.

with continuos air flow, unconfined micrometeorological method and mass balance analysis during 96 h was similar.

Correlation coefficient between observed and simulated NH_3 volatilization

The chamber measured and predicted NH_3 fluxes were plotted in Figure 6.

The R^2 for the correlation between predicted and observed ammonia volatilization during the calibration year (2002) was 0.53 which was less than that of the application year (2003), 0.72. The net correlation coefficient for the measured and predicted ammonia in 2002 and 2003 was 0.68 ($n = 114$, $p < 0.001$). The reason of the above difference may be explained by heavy rainfalls which increased water depth and consequently increased the resistance in ammonia loss from water during the calibration year. However, there is also an uncertainty about the change in pH of paddy water caused by the development of blue algae in the field, which needs more accurate description during the simulation.

CONCLUSION

During the rice growing period on 2002 and 2003, ammonia volatilized from straight urea was 6.04 kg N ha^{-1}, while that from coated urea was 1.46 kg N ha^{-1} which was less than 25% of straight urea. Therefore, coated urea application can significantly improve N use efficiency by mitigating of ammonia volatilization from the rice fields. The WNMM predictions of ammonia losses during these two rice growing seasons (2002 and 2003) were satisfactory to distinguish the applications of two urea forms as well as control, but slightly higher than the field measurements. In addition, the average R^2 for the correlation between predicted and observed ammonia volatilization during two years simulation (2002+2003) was 0.68 ($n = 114$, $p < 0.001$). The WNMM simulation predicted well in the silty clay loam paddy soil for ammonia volatilization from 2 years rice cropping system at Milyang in Korea.

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