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Full Length Article

Ammonia Volatilization from Direct Seeded Later-rice Fields as Affected by Irrigation and Nitrogen Managements

Linxian Liao[1], Xiaohou Shao[1], Renjing Ji[1], Tao Wen[1] and Junzeng Xu[1,2*]
[1]*College of water conservancy and hydropower engineering, Hohai University, Nanjing, 210098, China*
[2]*State key laboratory of hydrology-water resources and hydraulic engineering, Hohai University, Nanjing, 210098, China*
[*]For correspondence: xjz481@hhu.edu.cn

Abstract

Ammonia volatilization (AV) from direct seeded later-rice (DSR) fields was investigated based on plot experiment with different irrigation (traditional flooding irrigation (TI) and controlled irrigation (CI)) and nitrogen (farmers' fertilization practice (FF) and controlled released urea (CU)) managements. Seasonal AV losses were 64.0, 69.5, 33.0 and 24.6 kg N ha^{-1} from CIFF, TIFF, TICU and CICU fields, accounting for 18.3, 19.9, 13.7 and 10.3% of nitrogen inputs not as high as expected, and falling in the range reported in transplanted rice fields with the similar nitrogen treatments. Thus, it is difficult to answer the question if DSR practice will lead to significantly higher AV loss than transplanted cultivation. Mixed basal nitrogen fertilizer into muddy and frequently rainfall in the first forty days in rice season might account for the low AV loss percentages from DSR field in current research. Both nitrogen and irrigation management significantly affected AV loss from DSR fields, with the nitrogen management as the predominant factor. Compared with the farmers' fertilization, controlled released urea led to the reduced and retarded AV process. The controlled irrigation led to higher AV peaks immediately after nitrogen application in short period, but lower AV rates in long periods after the pulse AV emission than traditional flooding irrigation. The combination of controlled irrigation and controlled released urea is help to reduce AV loss from DSR field.

Keywords: direct seeded rice; Ammonia volatilization; Controlled released urea; Controlled irrigation

Introduction

Ammonia volatilization (AV) is one of the most important pathways of nitrogen (N) loss from rice fields, which accounted for about 10%–60% of nitrogen application (Fillery and De Datta, 1986; Xu *et al*., 2012). Large amounts of ammonia emitted into the atmosphere exerted toxic, eutrophic and acidifying effects on ecosystem (Van der Eerden *et al*., 1998; Emmett, 2007; Pinder *et al*., 2007; Liu and Diamond, 2008).

Many researches addressed on the AV loss from transplanted rice fields with different nitrogen management, including types, amount and application methods of nitrogen fertilizers. Controlled released urea (CU), deep fertilization**,** and urease inhibitors were always considered as important methods to reduce AV loss from rice fields (Zhu *et al*., 1989; Wang *et al*., 2007; Li *et al*., 2008b; Hayashi *et al*., 2008; Pacholski *et al*., 2008; Sanz-Cobena *et al*., 2008; Scivittaro *et al*., 2010; Xu *et al*., 2012). Meanwhile, water-saving irrigation, which was widely adopted in rice cultivation to cope with water scarcity (Mao, 2001; Bouman *et al*., 2007), led to change of nitrogen losses and nitrogen balance in rice fields. The influence of water management or combined water and nitrogen managements on AV loss from rice paddies arose as a new issue recently (Li *et al*., 2008a; Xu *et al*., 2012). Scivittaro *et al*. (2010) indicated that moist soil resulted in higher AV losses than muddy soil. Li *et al.* (2008a) and Xu *et al*. (2012) found the first flooding–drying cycle after N fertilization led to higher AV loss in the short period than flooding irrigation, but multi wet–dry cycles are likely to reduce the seasonal AV loss from transplanted rice fields, and concluded that a higher water level during the first flooding–drying cycle period after surface fertilizer application was necessary to mitigate AV loss from the zero-drainaged or non-flooding irrigated rice fields. Furthermore, the combination non-flooding irrigation and controlled released urea was effective to reduce AV loss from transplanted rice fields (Xu *et al*., 2012). Thus, nitrogen and water managements are important practices linked with AV loss from the traditional transplanted rice fields.

With the rural economic development and agricultural restructuring in developing countries, direct seeded rice (DSR) cultivation has been established and adopted as a substitute for transplanted rice due to the advantage of labor-saving (Bhushan *et al*., 2007; Gangwar *et al*., 2008;

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Farooq *et al*., 2011). When transplanted rice cultivation was replaced by DSR, the nitrogen losses by AV, surface runoff and leaching, and nitrogen uptakes of crop would change definitely, that put forward a request of appropriate management for nutrient and irrigation (Farooq *et al*., 2009, 2011). Regarding AV loss, most of the mentioned researches were conducted in traditional transplanted rice fields, with only few results from DSR fields. Watanbe *et al.* (2009) found AV loss (17.7%, in Can Tho) was higher from DSR fields than from conventional transplanted rice fields (5.5–17.4%, in Bac Giang and Hanoi). Zhang *et al.* (2011) found non-tillage practice used in DSR fields resulted in higher AV loss than from conventional tillage rice fields. A pot experiment focusing on the AV loss from DSR fields in gemmiparous and early seedling stages indicated that monthly AV loss from rice fields with different nitrogen managements accounted for 27.6-59.7% of nitrogen inputs, which was much higher than AV loss from conventional transplanted rice fields with the similar nitrogen managements. The absence of crop uptake and canopy roof, the very shallow water conditions in DSR fields favored the AV process during gemmiparous and seedling stages (Xu *et al*., 2013). Thus, the DSR practice, which was preferred by farmers due to the advantage of labor-saving, might favor the AV process from flooding rice paddies. But detail information about seasonal AV process from DSR fields as affected by practice of irrigation and nitrogen managements is still unknown, which is essential for appropriate water and nutrient management in DSR fields.

In current research, field experiment was conducted aiming to reveal the influence of combined water and nitrogen managements on AV loss from DSR fields.

Materials and Methods

Site Description

Plot experiment was conducted in 2011 at Nanjing Vegetables Scientific Research Institute (31° 56′ N, 118° 37′ E), Jiangsu, China. This region has a subtropical monsoon climate, with average annual air temperature of 15.6 °C and mean annual precipitation of 1,107 mm. The soil in the top 20 cm was water loggogenic paddy soil (Gong, 1999), with the texture of silty clay loam. Total nitrogen, total phosphorus and organic matter contents were 1.51, 0.21 and 13.2 g kg^{-1}, respectively, and soil pH was 6.85.

Experiment Design

There were two irrigation treatments (traditional flooding irrigation TI and non-flooding controlled irrigation CI) and two fertilization treatments (farmers' fertilization practice FF and CU) in the experiment. The experiment, with all four treatments (TIFF, CIFF, TICU and CICU), was laid out in 12 plots (2 m×5 m) in a randomized complete block design (RCBD) two factorial arrangement with three replications. In flooding irrigation fields, 30-50 mm standing water (up to 10 mm in gemmiparous and early seedling stage) was maintained except in later tillering and yellow maturity period. For the controlled irrigation treatment, flooding water (up to 50 mm for less than 5 days) was maintained in rice fields only during the period for fertilization, pesticide applications and rainfall harvesting, otherwise irrigation was applied only to keep soil moist. The lower and upper thresholds of soil moisture for controlled irrigation were 80% of saturated soil moisture and 10mm ponding water in gemmiparous and seedling stage, and in other stages were the same to the thresholds reported by Xu *et al.* (2012) in transplanted rice. Fertilization records in both fertilization treatments were listed in Table 1. The basal fertilizer was mixed into the muddy to a depth about 10 cm, and the additional fertilizers were dissolved in the water and poured into the plots evenly during irrigation. The controlled released urea used in current research was sulfur-coated urea, in which nitrogen content is 42%, provided by Kingenta Ecological Engineering Group Co., Ltd., China. Rice seeds (variety of Nanjing 42, pre-germinated with dry-raised nurse seed coat for 24 h) were broadcast evenly onto the paddy soil surface in dosage of 40 kg dry seeds ha^{-1}on July 4, 2011.

Sampling and Measurements

Samples for AV rates measurement were collected via the polyvinyl chloride polymer ventilation collectors (height = 20 cm, diameter = 14 cm), with a phosphoglycerol-soaked sponge inside as the absorbent (Wang *et al*., 2004). After each nitrogen fertilization, samples were collected daily at 10:00 am for the first 5 days, and then at 3-5 days interval. The phosphoglycerol soaked sponges taken out from the collectors were immediately immersed into 300 mL of 1.0 mol L^{-1} KCl solution in 500 mL containers. Then, the containers were sealed and shaken for one hour on a reciprocating shaker. The ammonia nitrogen concentrations in the extracted solutions were analyzed using an ultraviolet-visible spectrophotometer (Rayleight UV1800), and the AV rate was calculated using Equation 1:

$$R_{AV} = \frac{M}{A \cdot D} \times 10^{-2} \qquad (1)$$

Where, R_{AV} is the AV rate (in kg N $ha^{-1}d^{-1}$), M is the amount of ammonia nitrogen in the extracted solution or in the sponge (in mg N), A is the cross-sectional area of the ventilation collector (in m^2), and D is the sampling interval (in days).

Soil moisture and water layer were measured by using WET soil moisture sensor (Delta-T, UK) and vertical rulers fixed in the plots, to determine the time for irrigation. Daily meteorological data, including sunshine hours, minimum, maximum temperature, wind velocity and rainfall, were recorded using an automatic weather station (Fig. 1).

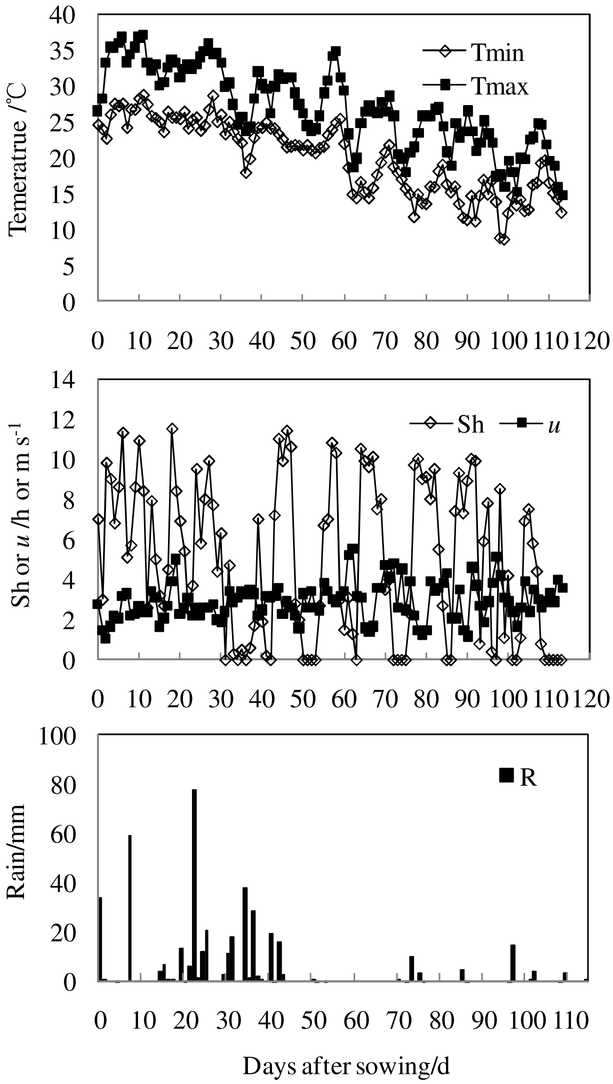

Fig. 1: Weather conditions of daily minimum temperature (T_{min}), maximum temperature (T_{max}), sunshine hours (S_h), wind velocity (u) and rainfall (R)

Surface water samples were collected from rice fields and stored in 250 mL glass conical flasks, and ammonium nitrogen contents in the surface water was determined.

Statistically Analysis

Multiple comparisons for AV loss from DSR fields were determined by Tamhane's tests at 0.05 probability level. Correlation coefficients were calculated to reveal the relations between AV rates and meteorological variables. Analysis of variance (MANOVA, multivariate analysis of variance) was used to measure the impact of nitrogen and water management on AV rates through calculation of the mean differences. The statistical analysis was performed using SPSS software for Windows (SPSS 13.0, Inc., Chicago, IL).

Results

Ammonia Volatilization Rates

AV processes from DSR rice fields were almost the same between treatments with the same nitrogen management (Fig. 2). In CIFF and TIFF treatments, there were three pulse AV fluxes lasting about one week immediately after each nitrogen application. Peak AV rates were 8.69 and 8.57 kg N ha^{-1} d^{-1} immediately after the basal fertilizer in TIFF and CIFF treatments, then decreased to 0.56 and 0.96 kg N ha^{-1} d^{-1} in one week. The peaks after tillering fertilizer were 13.0 and 9.7 kg N ha^{-1} d^{-1} in CIFF and TIFF paddies, which were the maximum in the whole season, then reduced to less than 1 kg N ha^{-1} d^{-1} within one week after nitrogen fertilization. The nitrogen application rate for basal fertilizer was 198 kg N ha^{-1}, much higher than the rate for tillering and panicle fertilizer (66 kg N ha^{-1}), but the AV rates were higher following the tillering fertilizer than basal fertilizer. It implied that the AV process was reduced by incorporating nitrogen into soil. The nitrogen dosage were the same for tillering and panicle fertilizer, but AV rates after panicle fertilizer (2.13 and 1.74 kg N ha^{-1} d^{-1} in CIFF and TIFF paddies) were much lower, due to poor ventilating condition under high canopy shelter and low air temperature. For TICU and CICU treatments, there were much lower peaks of AV (3.03 and 2.63 kg N ha^{-1} d^{-1}) than in TIFF and CIFF treatments. But during the non-pulse emission period, the AV rates were higher from TICU and CICU treatments than the TIFF and CIFF. It indicated that nitrogen management is the dominate factor in regulating the AV process from DSR rice fields, and controlled released urea led to reduced and retarded AV process.

Compared with the traditional flooding irrigation, non-flooding controlled irrigation led to slight change in AV process. Controlled irrigation always led to higher AV peaks after nitrogen application in short period, but lower AV rates in non-pulse emission periods. Peak AV rates after tillering and panicle fertilizers were 13.0 and 3.03 kg N ha^{-1} d^{-1}in CIFF and CICU treatments, higher than the peaks in TIFF and TICU treatments (9.7 and 2.63 kg N ha^{-1} d^{-1}).

Seasonal Ammonia Volatilization

The seasonal AV losses were calculated as 64.0, 69.5, 33.0 and 24.6 kg N ha^{-1} from DSR fields with CIFF, TIFF, TICU and CICU treatments, respectively (Table 2), accounting for 18.3, 19.9, 13.7 and 10.3% of seasonal nitrogen inputs. Fig. 2 also indicated the pulse emissions lasting for about one week immediately after nitrogen application in FF nitrogen treatment. Weekly AV losses immediately after nitrogen application from DSR fields were 55.4, 52.7, 9.1 and 7.2 kg N ha^{-1} for CIFF, TIFF, TICU and CICU treatments, respectively (Table 2), accounting for 86.5, 75.8, 27.6 and 29.4% of seasonal cumulative AV losses from rice fields. One month AV losses after basal application in TICU and CICU treatments were 21.2 and 17.8 kg N ha^{-1}, accounting

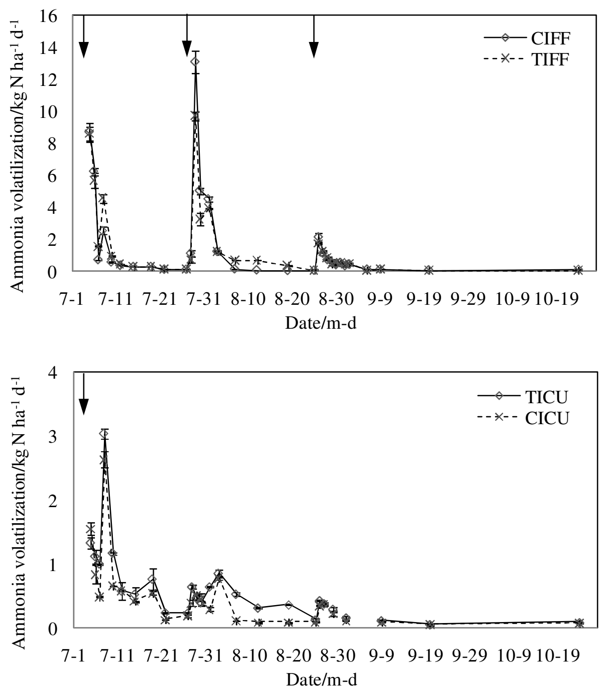

Fig. 2: Ammonia volatilization flux from direct seeded rice field with different irrigation and nitrogen managements (arrows indicated the nitrogen application, error bars error bars indicate the standard deviation)

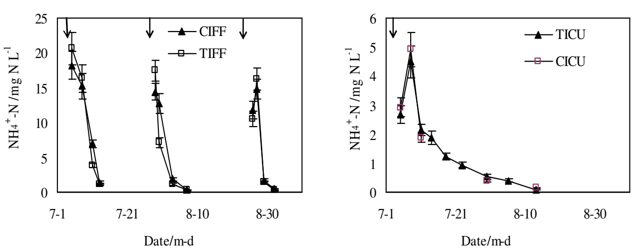

Fig. 3: Ammonium nitrogen contents in surface water of DSR fields following nitrogen application (arrows indicated the nitrogen application, error bars error bars indicate the standard deviation)

for 64.3 and 72.2% of seasonal AV losses. It confirmed again that controlled released urea resulted in much reduced and retarded AV process than farmers' fertilization treatment. Non-flooding controlled irrigation might lead to more AV loss than traditional flooding irrigation during pulse emission period, but a slight less AV loss totally in the whole rice season.

Discussion

A few studies reported that DSR resulted in higher AV loss than transplanted rice cultivation. Watanabe *et al.* (2009) found AV losses from DSR fields (17.7%, in Can Tho) was higher than those from traditional transplanted rice fields (5.5–17.4%, in Bac Giang and Hanoi). AV losses from non-tillage DSR fields were reported as 27.6 and 36.7 kg N ha^{-1} in 2009 and 2010 in central China, accounting for 13.2 and 17.5% of seasonal nitrogen inputs (Zhang *et al.*, 2011). A pot experiment carried focusing on the AV loss from DSR rice pots in gemmiparous and early seedling stages indicated that monthly AV loss from DSR rice fields might as high as 45.1%, 30.6% and 27.6% of nitrogen inputs for 5 cm deep application of ammonium bicarbonate, urea and controlled released urea. Those AV rates were much higher than the results from transplanted rice field, partially due to the influence of DSR practice (Xu *et al*., 2013). In current experiment, the percentages of AV loss to nitrogen inputs were almost the same to the results from DSR field by Watanabe *et al.* (2009) and Zhang *et al.* (2011), but much lower than the result by Xu *et al*. (2013) from a DSR pot. The low AV rates in current experiment might be ascribed to the practice of mixing large amount of the basal nitrogen fertilizer (account for 60% and 100% of seasonal nitrogen inputs in farmers' fertilization and controlled released urea treatments) into muddy, and the frequently rainfall in the first forth days (as in Fig. 1). Thus, the AV loss from DSR fields in current research was not as high as expected.

In current research, seasonal AV loss from the DSR fields with farmers' fertilization treatment was 64.0-69.5 kg N ha^{-1}, accounting for 18.3-19.9% of season nitrogen inputs (300 kg N ha^{-1}). Compared with the results with similar nitrogen inputs in transplanted rice fields, it was higher than the results of 11.3% in Shenyang (Chen *et al*., 2007), 11.7% in Chonnam (Lim *et al*., 2009), 11.2-12.9% in Jiaxing (Li et *al*., 2008a), 13.6-14.3% in Changsu (Li *et al*., 2008a), but lower than the results of 34.7% in Changsu (Li *et al*., 2008b), 25% in Wuxi (Xue *et al*., 2011), 25.9-36.5% in Changsu (Wang *et al*., 2007), and 31.1-36.1% in Kunshan (Xu *et al*., 2012). For controlled released urea treatments, the AV loss from the DSR fields in current research was 24.6-33.0 kg N ha^{-1}, accounting for 10.3-13.7% of season nitrogen inputs (240 kg N ha^{-1}). These percentages fell in the range of AV rates reported in transplanted rice field with the same nitrogen management. The percentage of AV loss to nitrogen inputs was reported as 8.0% in Wuxue (Cao *et al*., 2010), 0.5% in Yingtan (Wang *et al*., 2011), 1.1-5.6% in Changsu (Wang *et al*., 2007; Li *et al*., 2008b), 13% in Wuxi (Xue *et al*., 2011), and 13.2-18.5% in Kunshan (Xu *et al*., 2012). In current research, the AV loss percentage in the DSR fields fell in the ranges reported in transplanted rice fields with the similar nitrogen treatments. Thus, it is difficult to answer if DSR practice will lead to significantly higher AV loss than transplanted cultivation.

The degree of AV loss differs with types, dosages and application methods of nitrogen fertilizers (Wang *et al*., 2007; Hayashi *et al*., 2008; Xu *et al*., 2012). Pulse AV immediately after nitrogen application (Fig. 2) confirmed

Table 1: Fertilization records for different treatments

Treatments†	Basal fertilizer, July 4 (kg N ha^{-1})	Tillering fertilizer, July 26 (kg N ha^{-1})	Panicle fertilizer, August 24 (kg N ha^{-1})
TIFF, CIFF	198 (Compound fertilizer, 660 kg ha^{-1}; ammonium chloride, 381 kg ha^{-1})	66 (Urea, 143 kg ha^{-1})	66 (Urea, 143 kg ha^{-1})
TICU, CICU	240 (Control released urea, 571 kg ha^{-1})	0	0

† TIFF, CIFF, TICU and CICU are traditional flooding irrigation + farmers' fertilization practice, traditional flooding irrigation + controlled released urea, controlled irrigation + farmers' fertilization practice, , controlled irrigation + controlled released urea

‡ N, P_2O_5, and K_2O contents in the compound fertilizer are 16%, 16% and 16%. N contents in ammonium chloride, urea and control released urea are 24.2%, 46.2% and 42.0%

Table 2: Seasonal and weekly ammonia volatilization after nitrogen fertilization

Treatments	Seasonal		Weekly after N fertilization	
	AV losses Kg ha^{-1}	Percents to N inputs %	AV losses Kg ha^{-1}	Percents to seasonal losses %
CIFF	64.0a	18.3	55.4a	86.6
TIFF	69.5a	19.9	52.7a	75.8
TICU	33.0b	13.7	9.1b (21.2) †	27.6 (64.3) †
CICU	24.6c	10.3	7.2b (17.7) †	29.4(72.2) †

Means in the same volume followed by the same letter are not significantly different (p<0.05) by *Tamhane* test

† Figure in the bracket is monthly ammonia volatilization after control releases urea application and the percentages to seasonal ammonia volatilization

Table 3: MANOVA results for ammonia volatilization losses from DSR fields

Influence factor	SS	F	p
Nitrogen	4294.6	3705.5	0.000***
Irrigation	152.1	131.2	0.000***
Interactive effect	5.2	4.44	0.068
Error	9.2		

***indicate the correlation is significant at p<0.001

Table 4: Correlations between ammonia volatilization and meteorological parameters

Treatment†	High AV rates period					Low AV rates period				
	Sh	Tmin	Tmax	*u*	Tavg	Sh	Tmin	Tmax	*u*	Tavg
TIFF (n=13/18)	0.416	0.250	0.026	0.084	0.113	0.445*	0.496*	0.385	0.234	0.485*
CIFF (n=13/18)	0.334	0.208	0.017	0.187	0.086	0.460*	0.409	0.524*	0.265	0.484*
TICU (n=11/15)	0.479	0.193	0.083	0.125	0.202	0.150	0.751*	0.533*	0.168	0.700*
CICU (n=11/15)	0.424	0.189	0.055	0.122	0.095	0.083	0.575*	0.467	0.127	0.570*

*indicate the correlation is significant at p<0.05

†Numbers at left and right side of the slash are the number for high and low AV rates periods, separately

that nitrogen application is the dominant factor in regulating AV loss form DSR fields. The dosage of basal fertilizer in farmers' fertilization treatments was three times of nitrogen amount for tillering or panicle fertilizer. The absence of canopy shelter and crop uptakes following basal fertilizer were expected favored the AV process in DSR fields, but the peaks after basal fertilizer were not much higher than the peaks after tillering fertilizer. That might be ascribed to the basal fertilizer was mixed into soil, but the tillering fertilizer was broadcasted to surface water (Obcemea *et al*., 1988; Zhu *et al*., 1989; Hayashi *et al*., 2008). Controlled released urea in dosage of 240 kg N ha^{-1} was mixed into soil all at once as basal fertilizer, higher than the basal fertilizer dosage in farmers' fertilization treatment. But the AV rates in DSR fields following controlled released urea application were much lower than the peaks in farmers' fertilization treatment following basal fertilizer. And the percentages of seasonal AV loss to nitrogen inputs in controlled released urea DSR fields were 10.3-13.7% of nitrogen inputs, also lower than the percentage in farmers' fertilization treatments (18.3-19.9%). Controlled released urea always resulted in less AV loss form transplanted rice field(Wang *et al*., 2007; Li *et al*., 2008b; Cao *et al*., 2010; Wang *et al*., 2011; Xue *et al*., 2011), because the substrate concentration of AV was low due to the slowly release of urea. It was confirmed again in DSR fields.

There are several reports on the influence of water management on AV loss from rice field. It was reported that high water level resulted in low AV losses from flooding transplanted rice fields (Li *et al*., 2008a). In current research, first wetting-drying cycle immediately after nitrogen application led to increased AV loss in short period, and multi wetting-drying cycles in controlled irrigation treatments resulted in reduced seasonal AV loss from DSR fields. Similar result was reported recently in transplanted rice fields (Xu *et al*., 2012).

MANOVA analysis indicated that both nitrogen and water management significantly affected AV losses from DSR fields (Table 3), and the former is the dominant factor. The mean variance for nitrogen management accounted for 96% of the sum of the squared deviation for AV losses from DSR field. The interactive effect between water and nitrogen managements on AV loss from DSR fields was not significant.

Ammonium nitrogen contents in surface water dominated the AV loss from transplanted rice fields (Jayaweera and Mikkelsen, 1991; Li *et al*., 2008a; Watanabe *et al*., 2009). It was confirmed it in DSR fields in current experiment. For farmers' fertilization treatments, ammonium nitrogen contents in surface soil were as high as 15-20 mg N L^{-1} in 2-3 days after nitrogen application, and reduced to as low as <1.0 mg N L^{-1} in 7-9 days after nitrogen application (Fig. 3). The period of pulse AV emission is consistent to the period when the ammonium nitrogen contents were high in surface water (Fig. 2 and 3). For controlled released urea treatments, ammonium nitrogen contents after nitrogen application were lower than in farmers' fertilization treatment. The ammonium nitrogen contents reduced gradually from the peaks about 4-5 mg N L^{-1} to < 1.0 mg N L^{-1} in about 20 days (Fig. 3), during which the AV rates were relative high (Fig. 2).

Correlations between AV rates and meteorological variables were different between the period with high AV rates and the period with low AV rates (Table 4). For TIFF and CIFF treatments, correlations to metrological parameters during low AV rates periods were higher than the period with high AV rates. It indicated the ammonium nitrogen contents in surface water dominated the AV rates during the pulse emission period. For TICU and CICU treatments, it is the same except for the influence of sunshine hours. Comparison between irrigation treatments indicated that AV rates from controlled irrigation fields were less sensitive to meteorological variables than from traditional flooding irrigation fields. That may be ascribed to wetting-drying cycles in controlled irrigation fields bring more nitrogen into rizophere soils (Xu *et al*., 2012).

Conclusion

Seasonal AV loss was 64.0, 69.5, 33.0 and 24.6 kg N ha^{-1} from DSR field with CIFF, TIFF, TICU and CICU treatments, accounting for 18.3, 19.9, 13.7 and 10.3% of seasonal nitrogen inputs. These percentages of AV loss to nitrogen inputs from DSR fields were not as high as expected, and fell in the range reported in transplanted rice fields with the similar nitrogen treatments. Thus, it is difficult to answer the question if DSR practice will lead to significantly higher AV loss than transplanted cultivation. Mixed basal nitrogen fertilizer into muddy and frequently rainfall in the first forty days of rice season might account for the low AV loss from DSR fields in current research. Both nitrogen and water management significantly affected AV loss from DSR fields, and nitrogen was the predominant factor. The combination of controlled irrigation and controlled released urea is help to reduce AV loss from DSR field.

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