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Ammonia emissions from soil water of wheat field as affected by different nitrogen and irrigation strategies

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ABSTRACT

Agricultural activities should be responsible for substantial amounts of ammonia (NH_3) emissions. The fertilization and irrigation strategies both make great contributions to potential N losses via volatilization, but there are very few data regarding NH_3 emissions as affected by the combination of application time of N fertilization and irrigation treatments. The aim of this experiment is to provide the field data on N losses due to NH_3 volatilization following urea application and assess the influence of soil properties and environmental condition on emissions. The experiment including a combination of application time of N fertilization and irrigation treatments was carried out using the venting method. NH_3 volatilization was monitored within 30 d following urea application. NH_3 loss can fall down to the background level with irrigation or rainfall events following urea application. Otherwise, up to 30% of the N applied will be lost through volatilization. Large amounts of NH_3 emissions occur only if two conditions are simultaneously satisfied: high ammonium nitrogen concentration and low soil water content in topsoil. Irrigation following urea application at jointing stage (JFI) can be adopted in the local management practice to minimize volatilization and maintain financial benefits.

Keywords: Ammonia emissions; Soil water; Wheat field; Nitrogen and irrigation strategies

1. Introduction

With the increasing global demand for food and energy, chemical inputs, especially nitrogen (N) fertilizer, are of utmost importance to promote crop yield increases in modern agricultural production [1]. To obtain high grain yield, a great amount of N fertilizer far greater than crop demand is applied into the field [2]. Urea is widely used as the predominant source of N fertilizer in agriculture worldwide [3], accounting for over half of the global fertilizer N consumption [4].

The loss of applied N is of concern because of excess and inappropriate application of fertilizers [5,6]. Substantial N can be lost through volatilization of ammonia (NH_3), emissions of NO_x (N_2O, NO and NO_2) and dinitrogen (N_2), leaching of nitrate (NO_3^-) and surface runoff [7]. NH_3 volatilization is an important pathway of N loss after N fertilizer is applied into the soil [8,9]. NH_3 volatilization from urea fertilizer varies from place to place. Some reported losses of N due to NH_3 volatilization from urea are less than 40% of the N applied. However, other NH_3 losses from urea have been

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reported up to 50% or more of the N applied [10]. Attention should be focused on NH_3 volatilization not just because of low N utilization efficiency, but also because of significant adverse effect on the environment. Continuous and excess N loads from the release of NH_3 has caused serious ecological and environmental problems, such as eutrophication of surface water bodies, soil acidification, secondary source of N_2O production, formation of particulate 2.5-µm aerosols that lead to potential adverse effects on human health and changes in biodiversity [11,12].

NH_3 volatilization is associated with soil properties and environmental factors, such as soil moisture, pH, texture, organic matter, temperature, surface residue, rainfall, and wind speed [13]. To achieve the dual goals of reducing NH_3 volatilization and obtaining high grain yield, some effective approaches, such as fertilization, irrigation and cultivation managements, have been proposed to be adopted in agricultural practices [14]. However, many approaches to reducing NH_3 volatilization did not have remarkable effect on the grain yield [15,16]. Hence, the purpose of the current study was to quantify the NH_3 volatilization losses after application of urea as affected by three top dressing periods and irrigation treatments and assess the influence of soil properties and environmental condition on NH_3 volatilization.

2. Materials and methods

2.1. Description of the experimental site

The field experiments were carried out at the Tai'an Experimental Station (36°09′N, 117°09′E, and 128 m above sea level) of Shandong Agricultural University; Shandong Province, China from October 2009 to June 2010 and from October 2010 to June 2011. This region was characterized as a semi-humid temperate continental monsoon climate. The soil was classified as a sandy loam, with average pH of 6.8, organic matter of 13.5 g kg^{-1}, total N of 0.89 g kg^{-1}, available N of 77.8 mg kg^{-1}, available P of 26.6 mg kg^{-1}, available K of 75.2 mg kg^{-1} in the 0–20 cm soil layer.

2.2. Experimental setup

The experiments were conducted to evaluate volatilized NH_3 in relation to three nitrogen topdressing periods and irrigation treatments that are shown in Table 1. Based on the results of 2010, nine treatments were added later in 2011 to determine the influence of irrigation on NH_3 volatilization. The field was split into two blocks, which were separated by at least 1 m to avoid interactions between irrigation treatments (2011). Other treatments were arranged in a randomized complete block design with three replications. 112.5 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1} as basal fertilization and the rest 112.5 kg N ha^{-1} as topdressing were applied along with irrigation. Except for seedling and topdressing, there was no irrigation during the whole growing season of winter wheat (*Triticumaestivum* L.). Summer maize (*Zea mays*) was the previous crop and all the straw was crushed to the field.

The short dashes in the table donate no N fertilizer application or irrigation.

2.3. NH_3 emission measurements

NH_3 volatilization was monitored using venting method as described below [17]. The vented chamber was 10 cm high and 15 cm in internal diameter, which was made of rigid polyvinyl chloride (PVC) tube. Two circular sponges each spread with 15 mL phosphate-glycerol solution (50 mL analytical phosphate and 40 mL glycerol diluted to 1000 mL with pure water) were placed into the chamber. The sponge inside the chamber absorbed NH_3

Table 1
The nitrogen and irrigation strategies

Year	Treatment	N fertilizer application		Irrigation	
		Time	Rate (kg ha^{-1})	Time	Amount (mm)
2010	SF	2010/3/21	112.5	2010/4/2	60
	JF	2010/4/10	112.5	2010/4/2	60
	BF	2010/4/30	112.5	2010/4/2	60
2011	SF	2011/3/20	112.5	–	–
	SFI	2011/3/20	112.5	2011/3/20	60
	SI	–	–	2011/3/20	60
	SCK	–	–	–	–
	JF	2011/4/9	112.5	–	–
	JFI	2011/4/9	112.5	2011/4/9	60
	JI	–	–	2011/4/9	60
	JCK	–	–	–	–
	BF	2011/4/29	112.5	–	–
	BFI	2011/4/29	112.5	2011/4/29	60
	BI	–	–	2011/4/29	60
	BCK	–	–	–	–

volatilized from the soil and the top one was placed to keep off NH_3 from the ambient air.

The vented chambers were installed 1 cm into each plot immediately after the nitrogen fertilizer was applied. NH_3 samples were replaced at 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30 d (2010) and 1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20, 25, 30 d (2011) after application (DAA) of the fertilizer. The collected NH_3 from sponge inside the chamber was for the time between sampling dates. Collected samples were extracted with 300 mL of 1 M KCl and shaking for 60 min. AA3 continuous flow analytical system (Bran+Luebbe, Germany) was used to analyze NH_4^+ from the samples. NH_3 volatilization rate (*R*) was evaluated as the average volatilization per day between two replacements of the acid trap, which was calculated as follows:

$$R\left(kgNha^{-1}d^{-1}\right)=\frac{M}{\left(A\times D\right)\times 10^{-2}} \qquad (1)$$

where *M* is the NH_3 (mg N) absorbed by sponge inside the chamber, *A* is the cross-sectional area (m^{-2}) of the vented chamber. *D* (d) is the duration between two sampling periods. 10^{-2} is the factor of unit conversion. NH_3 volatilization losses (*L*) were evaluated as the percentage of N lost as NH_3, which were calculated as the following equation:

$$L\left(\%of\ applied N\right)=\frac{\Sigma\left(R_i+R_{i+1}\right)}{\left[2\times\left(t_{i+1}-t_i\right)\times N\right]\times 100} \qquad (2)$$

where *R* is NH_3 volatilization rate (*kg N* ha^{-1} d^{-1}), *i* is the *i*th measurement, ($t_{i+1}-t_i$) is the days between two adjacent days of the measurements, and *n* is the total times of the measurements. *N* is the rate of applied nitrogen fertilizer.

2.4. Soil samples

Soil samples from depths of 0–10 cm were taken to determine soil ammonium nitrogen concentration and water content every time NH_3 volatilization was monitored. The samples were divided into two parts: one was stored at –20ºC from the time of collection until analysis of ammonium nitrogen; the other was dried to constant weight for water content.

2.5. Statistical analysis

Regression analysis was performed with the SPSS software packages (Version 18.0, SPSS Inc., Chicago, USA). All the figures were constructed using SigmaPlot 10.0 (Systat Software, San Jose, CA). To determine the statistical significance of the mean differences, Duncan tests were carried out at 0.05 probability level.

3. Results and discussion

3.1. Environmental condition

Atmospheric temperature and rainfall events were recorded at a nearby weather station 1 km away. Average atmospheric temperature of three topdressing periods during monitoring in 2010 and 2011 was similar (Fig. 1). In 2010, the average temperatures of three monitoring periods were 11.2, 15.1, and 20.3°C, respectively (Fig. 1a). Those in 2011 were 11.5, 17.2, and 19.8°C. Compared with 2010, large amounts of rainfalls occurred in 2011 despite a low frequency. Two significant rainfall events >50 mm (Fig. 1b) occurred on May 8 and May 10, 2011.

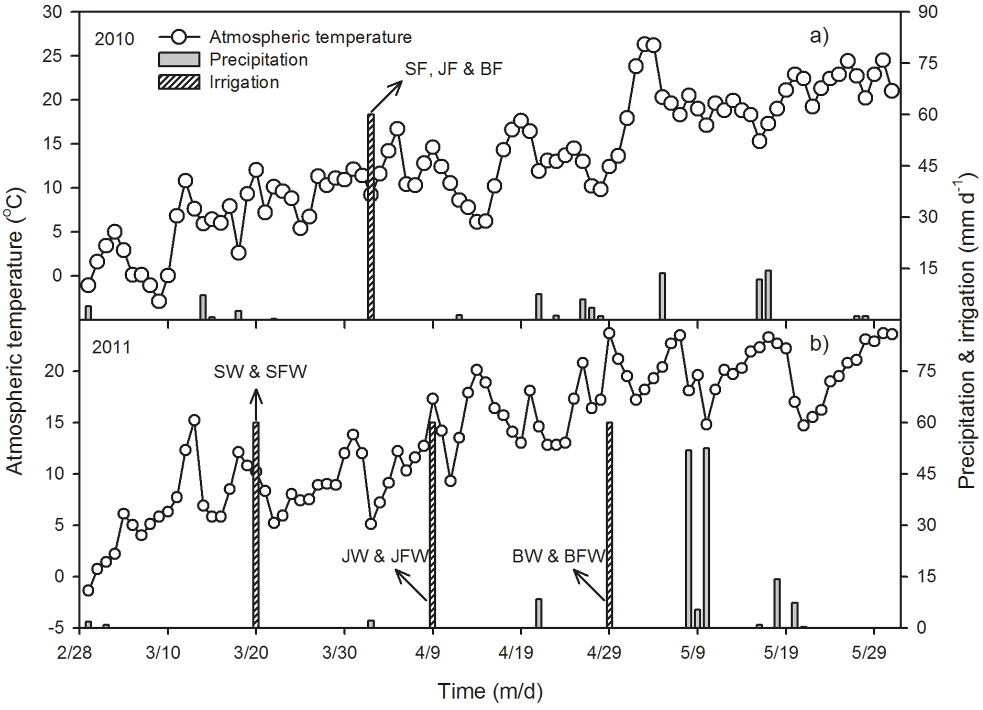

Fig. 1. Atmospheric temperature, precipitation and irrigation from a meteorological station located in the experimental field. Only these treatments above the arrows were irrigated at one time.

3.2. NH_3 volatilization rates

NH_3 volatilization rates increased above the background values immediately after urea was applied. Peaks in NH_3 volatilization for 2010 were observed 8 d after urea application in BF, 10 d in SF, but not until 16 d in JF. Not only was lower peak of NH_3 volatilization observed in JF, but they also occurred later after urea application than the other two treatments (Fig. 2a). This was likely the result of the irrigation before urea application which prevented NH_3 release from soil. The first peak rates for 2011 were reached 7 d after urea application in both JF and BF, and then 9 d in SF. Peak of volatilization in BF was lower than the other two treatments. There was a second peak of volatilization in 2011 at about day 15 that did not occur in 2010 (Fig. 2b). Evidently it was the irrigation on 2 April and the following high intensity rainfall events (Fig. 1a) that prevented NH_3 release from soil. The amount and intensity of rainfall determined the movement of urea or ammonium into the soil matrix, thereby affecting NH_3 volatilization [18]. There were no significant differences in NH_3 volatilization rate between the remaining treatments that are not listed in Fig. 2 The volatilization rates fluctuated around the background values, ranging from 0.00 to 0.11 kg N ha^{-1} d^{-1}. It can be inferred that N lost as NH_3 in these treatments was negligible. These results demonstrated that irrigation or rainfall is effective in mitigating NH_3 volatilization immediately following urea application. NH_3 volatilization losses were still substantial when irrigation or rainfall events occurred after urea hydrolysis.

There was an immediate step increase in ammonium concentrations in 0–10 cm soil after urea was applied into the soil (Figs. 3a, c, e). Ammonium concentrations in the fertilizer treatments (F) did not decrease until about 12 d after application, but ammonium concentration in BF decreased after 7 d because of the intensive rainfall events (51.8, 5.2 and 52.4 mm from Day 9 to 11, respectively). Ammonium concentrations in the irrigation following fertilization treatments (FI) decreased rapidly to the background value, although they increased more rapidly than the other treatments within the first 5 d following application. These results together with other literature evidence [19] illustrates that NH_3 volatilization rates coincide with ammonium concentrations in surface soil. NH_3 volatilization rates fell down rapidly as the substrate (ammonium) concentrations decreased. The soil water contents in irrigation treatments (FI and I) were always greater than in F and CK, but gradually the gaps between them began to be close (Figs. 3b, d, f). It seemed that ammonium concentrations and soil water content were two necessary conditions. Only both two certain conditions were satisfied did large amount of NH_3 volatilization occur: (1) there was a high ammonium concentration in topsoil; (2) soil water content in topsoil should be low enough. These results suggested that irrigation (or rainfall events) and appropriate N rate would be effective measures to mitigate NH_3 volatilization.

Temperature also played an important role in NH_3 volatilization. Except for JF in 2010, peak emission rates in SF were reached later than JF and BF (Fig. 2). The longer duration of emission in SF was likely the result of lower average temperature after urea was applied which limited hydrolysis of urea and nitrification. Nitrification potential is usually high in agricultural soils and ammonium is rapidly oxidized. A more rapid formation of ammonium and fast diffusion in the soil water and air likely resulted in higher NH_3 volatilization. Nevertheless, temperature did not appear to be as significant a factor as other soil and climatic variables [20].The total loss may not be less at low than at high temperature due to a longer period of high emissions.

3.3. NH_3 volatilization losses

As shown in Fig. 4c, measured background NH_3 volatilization losses were below 1.2% of the N applied, much

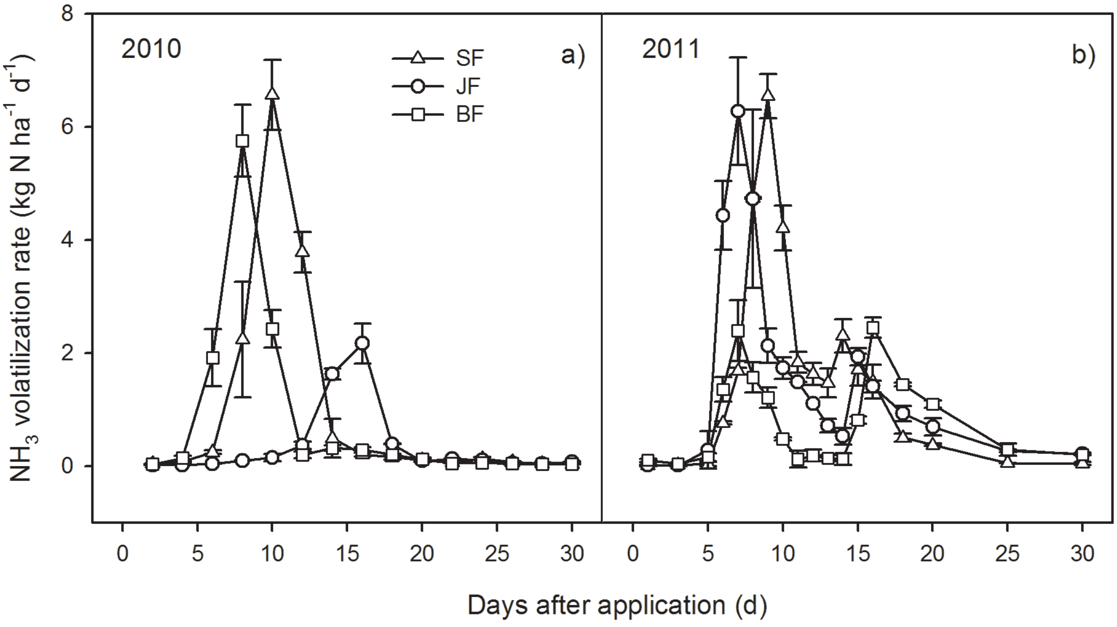

Fig. 2. NH_3 volatilization rate following urea application as affected by three topdressing periods.

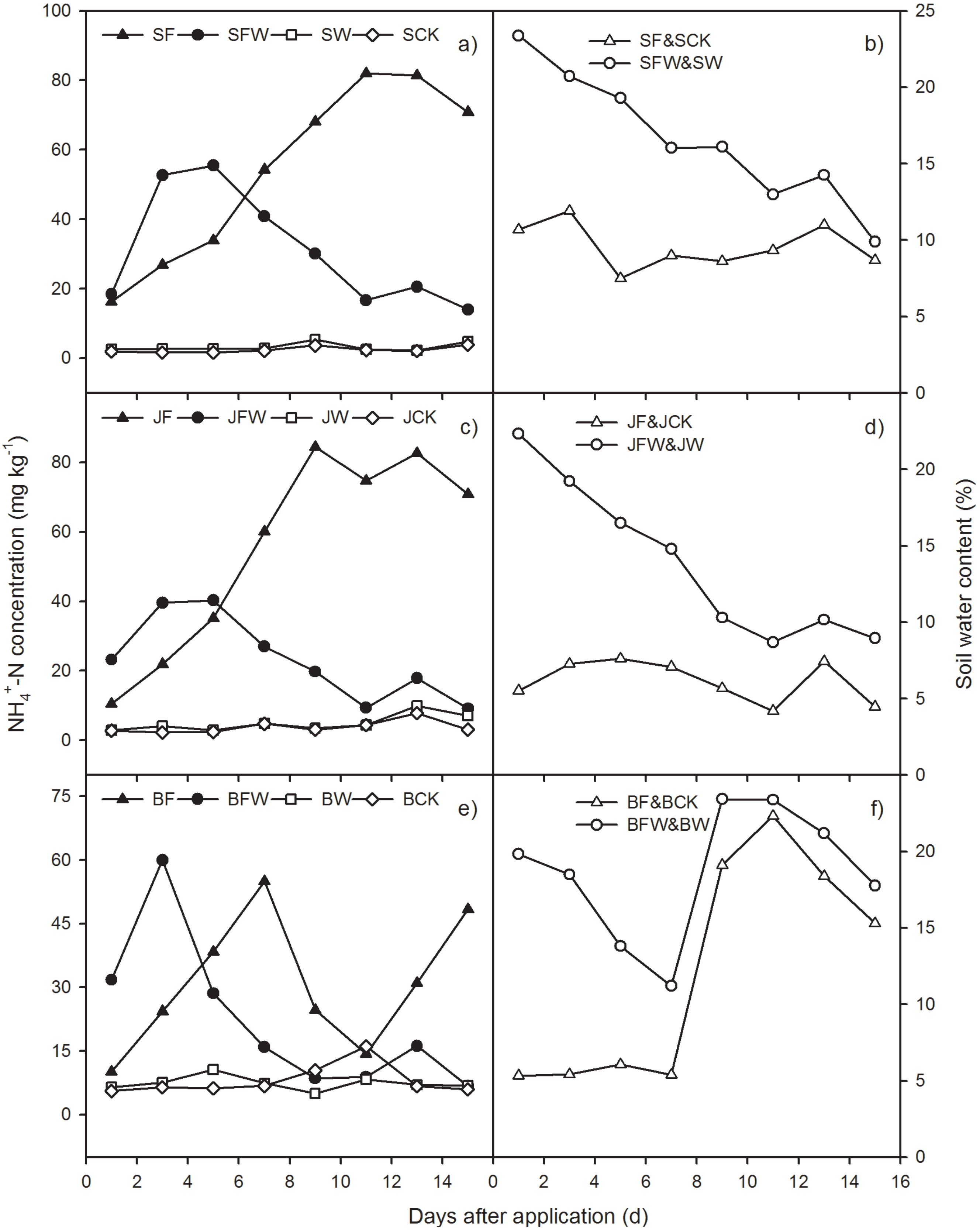

Fig. 3. Soil ammonium nitrogen concentration (a, c, e) and water content (b, d, f) following urea application from depths of 0–10 cm as affected by various nitrogen and irrigation strategies.

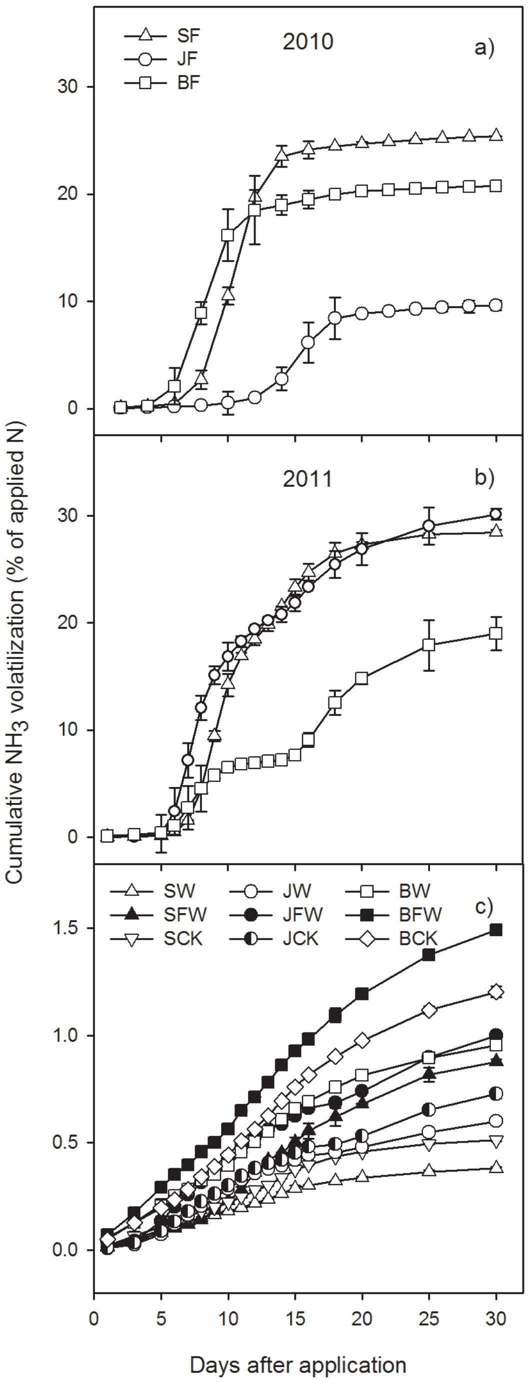

Fig. 4. Cumulative NH_3 volatilization following urea application as affected by various nitrogen and irrigation strategies. Ammonia volatilization losses were expressed as percentage of total N applied.

lower than those of the fertilizer treatments (F). So the results of determining approached the losses of the fertilizer treatments. Most of the total loss occurred from 5 to 15 DAA. BF in 2010 lost 20.8% of the N applied, which was lower than SF with loss of 25.4% of the N applied but higher than JF, which lost 9.6% of the N applied (Fig. 4a). SF in 2011 lost 28.5% of the N applied, which was slightly lower than JF with loss of 30.1% of the N applied but both higher than BF, which lost 19.0% of the N applied (Fig. 4b). Compared with these treatments, the remaining ones only lost few of the N applied. As described above, large amount of irrigation transported the urea directly into the soil matrix as a dissolved component, thus decreasing the substrate concentration of NH_3 volatilization before the hydrolysis of urea. Losses of the treatments J were lower than those of the corresponding treatments of B, but greater than the corresponding treatments of S (Fig. 4c). This illustrates that temperature also plays a key role in NH_3 volatilization, which matters less than irrigation (or rainfall events) and fertilization. Compared with the same topdressing period, the control treatments (CK) lost lower N applied than FI but higher than I. These results demonstrated that irrigation following urea would effectively mitigate NH_3 volatilization [10].

3.4. Grain yield

Grain yield of JF in 2010 was greater than SF and BF. No significant differences in grain yield were found between SF and BF (Fig. 5a). N fertilizer of JF was applied at the critical period when the winter wheat required a large amount of nutrients. The irrigation before fertilization, together with the N fertilizer, led to the gap in yield. Grain yield of JFI in 2011 was greater than SFI and BFI. There were also no significant differences in grain yield between SFI and BFI. Yields of the irrigation (I) treatments were lower than those of fertilization (F) treatments but greater the control treatments (CK) in the same topdressing periods (Fig. 5b). The differences in yields could be explained by the appropriate time of N fertilizer application and irrigation. The treatment JFI should be adopted to achieve the dual goals of reducing NH_3 volatilization and obtaining high grain yield.

4. Conclusion

Irrigation or rainfall events after N fertilizer application are effective in reducing NH_3 loss. High ammonium concentration and low soil water content in topsoil seem to be two essential condition of a large amount of NH_3 loss. Temperature also plays an important role in NH_3 volatilization, but is not as significant as irrigation (or rainfall events) and fertilization. Up to 30 percent of the N applied could be lost without

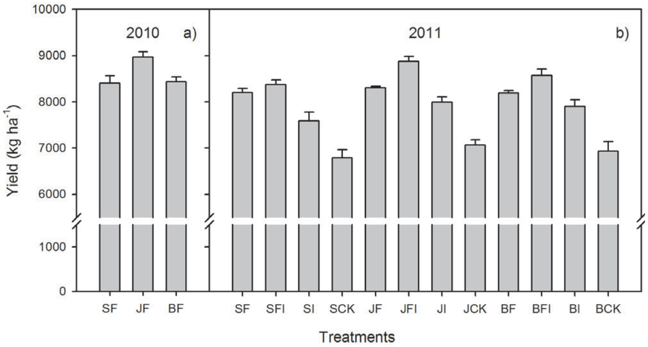

Fig. 5. Grain yields as affected by various nitrogen and irrigation strategies.

irrigation or rainfall events. Hence NH_3 volatilization is an important pathway of N losses in arid and semi-arid region where there is no irrigation and little rain. The treatment JFI can be recommended in the local management practice when NH_3 loss and grain yield are taken into consideration.

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