Ammonia volatilization with swine slurry injection and use of nitrification inhibitor

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ABSTRACT

The injection of nitrogen sources into the soil and use of nitrification inhibitor can improve the efficiency of applied nitrogen and minimize losses to the environment. The objective of this study was to evaluate the effect of swine slurry (SS) and urea in two modes of application in the soil (injected and surface), and the use of nitrification inhibitor on NH_3 volatilization in a controlled environment, upon varying soil texture and soil pH conditions. The experiment was conducted under controlled conditions, or a Rhodic Kandiudox and Typic Hapludult soil in a completely randomized design in a 4 x 2 x 2 x 2 factorial design with three replications. The study evaluated four fertilizers (urea, SS, SS +nitrification inhibitor (dicyandiamide-DCD) and control), two pH conditions (natural and limed) and two forms of fertilizer application (injected and surface), and two soils. The SS rate used was 21 m^3 ha^{-1}, and the rate of the inhibitor was 10 kg ha^{-1}. The evaluations consisted in daily accumulated ammonia volatilization up to 14 days, and the percentage of soil nitrogen loss. The injection of fertilizers reduced emissions of ammonia in both soils and, limed soil had higher N losses by volatilization. The inhibitor did not increase the emission of ammonia in both soils.

Key words: manure; dicyandiamide; emission; nitrogen.

RESUMO

Volatilização de amônia do solo com injeção de dejeto líquido suíno e inibidor de nitrificação

A injeção de fontes de nitrogênio no solo e o uso de inibidor de nitrificação podem melhorar a eficiência do nitrogênio aplicado e minimizar perdas para o ambiente. O objetivo deste trabalho foi avaliar o efeito do DLS e da ureia em dois modos de aplicação no solo (injetado e superficial), e o uso de inibidor de nitrificação sobre a volatilização de NH_3 em ambiente controlado, com condições variadas de textura e pH do solo. O experimento foi conduzido em condições controladas, em um Nitossolo e um Argissolo, com delineamento inteiramente casualizado, em esquema fatorial 4 x 2 x 2 x 2 com três repetições. Avaliou-se quatro fertilizantes (ureia, dejeto líquido suíno, dejeto líquido suíno+inibidor de nitrificação (dicianodiamida-DCD) e testemunha), duas condições de pH (natural e corrigido), duas formas de aplicação dos fertilizantes (injetado e superficial), e dois solos. A dose de dejeto suíno foi de 21 m^3 ha^{-1}, e a do inibidor foi de 10 kg ha^{-1}. As avaliações consistiram em mensuração da volatilização de amônia diária e acumulada até o 14º dia, e da porcentagem de N perdido em relação ao aplicado. A injeção reduziu as emissões de amônia em ambos os solos, e a correção do pH favoreceu as perdas de N por volatilização. O inibidor não aumentou a emissão acumulada de amônia em ambos os solos.

Palavras-chave: dicianodiamida; biofertilizante; emissão; nitrogênio.

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INTRODUCTION

Many areas dedicated to swine farming in southern Brazil may be impacted by excessive and successive applications of swine slurry (SS), resulting in environmental constraints. The application of this organic material to the soil surface may promote ammonia (NH_3) volatilization and cause losses of up to 50% of the applied nitrogen (N), reducing its fertilizing potential (Cameron *et al*., 2013).

Technologies used to mitigate the polluting effects and to enhance agronomic use of N present in animal wastes have been evaluated. The injection of SS is an recommended alternative and it is already adopted in countries of temperate climate, proving to be efficient in reducing volatilization of NH_3 (Pote & Meisinger, 2014). This reduction by soil injection is justified by the lower exposure to air and the increase in the adsorption of ammonium (NH_4^+) in the soil, due to the greater contact with soil particles (Webb *et al*., 2014).

Another alternative is the use of nitrification inhibitors, which have been investigated in many countries in order to reduce nitrate (NO_3^-) leaching (Zaman & Blennerhassett, 2010; Zhang *et al*., 2015; Gonzatto *et al*., 2016). Dicyandiamide (DCD) is one of the nitrification inhibitors used in other countries. This compound has bacteriostatic properties involved in the oxidation of NH_4^+ to nitrite (NO_2), reducing the action of bacteria *Nitrosomonas* (Singh & Verma, 2008), by temporarily blocking the ammonium monooxygenase enzyme, which prolongs permanence of NH_4^+ in the soil. Thus, it is necessary to evaluate whether the application of this inhibitor interferes with the levels of NH_4^+ of the soil and affects the losses of N by volatilization (Vander Zaag *et al*. 2011).

These strategies used to reduce the environmental impact of SS, such as the injection and the use of the nitrification inhibitor, may present variable results on the volatilization of NH_3 (Kim *et al*., 2012), depending on the soil conditions and the form in which the organic waste was applied.

Thus, the hypothesis of this work is that the combined use of the nitrification inhibitor and SS injection reduces N losses by NH_3 volatilization, which would increase the efficiency of the use of this organic material as fertilizer.

The objective of this work was to evaluate the effect of SS and urea in two modes of application in the soil (injected and superface), and the use of nitrification inhibitor on NH_3 volatilization in a controlled environment, upon varying conditions of texture and pH of the soil.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse under a completely randomized design, with three replications, in a 4 x 2 x 2 x 2 factorial scheme, which were, as follows: four fertilizers (urea, swine slurry (SS), SS+ nitrification inhibitor dicyandiamide-DCD) and control); two pH conditions (natural and corrected); two modes of fertilizer application (injected and surface); and two soils (clayey and sandy).

The experimental units consisted of polyethylene pots with a capacity of 700 mL, whose dimensions were 7.5 cm in diameter, containing 250 g of dry soil, maintained with moisture of 70% of field capacity (FC) for Rhodic Kandiudox (clayey soil) and 60% of FC for the Typic Hapludult (sandy soil). Moisture was previously tested, allowing aerobic conditions for biological activity and good physical condition, not causing deformation of the soil aggregates during the handling and setting up of the experiment.

Swine slurry was collected from anaerobic manure storage tanks from a production system of swine finishing. SS was characterized according to a methodology described by Tedesco *et al*. (1995), with dry matter of 156 g kg^{-1}; total-N: 8.2 kg m^{-3}; ammoniacal-N: 4.2 kg m^{-3}; nitric-N: 0.1 kg m^{-3}; pH: 6.6. The rate of SS applied was 21 m^3 ha^{-1}, based on the recommendation of 140 kg ha^{-1} of N to reach an yield of 8 Mg ha^{-1} of mayze (CQFS-RS/SC, 2016). For the mineral fertilizer, the conventional urea (45% N) was applied at the same N rate of the SS.

The nitrification inhibitor used was dicyandiamide (DCD). This product is presented as a white, synthetic powder, consisting of 81% of DCD and 6.5% of N- (n-butyl) thiophosphoric triamide (NBPT) in its formulation. It is commercially used in the United States and tested under experimental conditions in Brazil. The inhibitor was mixed to SS at the time of soil application at the rate of 10 kg ha^{-1} of active ingredient.

Fertilizer injection was performed on a tray by evenly mixing the sources of N (SS and urea (diluted in water)) with 250 g of soil. Moisture was standardized using water in the same volume of the SS, for the treatments with urea and in the control. For surface application, the sources of N were distributed with the aid of a pipette over soil surface in the pots.

The soils used in the study were a Rhodic Kandiudox, and a Typic Hapludult, collected in the 0.0-0.20 cm layer, air-dried and sieved in a 3-mm mesh sieve. The chemical and physical properties determined by methodologies described by Tedesco *et al*. (1995) and according to the methodologies described by Embrapa (1997), respectively, observed in the Rhodic Kandiudox are, as follows: pH ($_{water}$): 4.8; P: 2.9 mg dm^{-3}; K: 71 mg dm^{-3}; organic matter: 36 g kg^{-1}; sand 90 g kg^{-1}; silt: 160 g kg^{-1}; clay: 750 g kg^{-1}. For the Typic Hapludult, the characteristics are the following: pH ($_{water}$): 4.2; P: 3.1 mg dm^{-3}; K: 70 mg dm^{-3}; organic matter: 13 g kg^{-1}; sand 690 g kg^{-1}; silt: 70 g

kg^{-1}; clay: 240 g kg^{-1}. A portion of each soil had its pH adjusted to pH 6.0 by incubation for 30 days with dolomitic limestone (CaO: 29%, MgO: 19% and PRNT: 100%), as recommended by CQFS-RS/SC (2016).

The capture of soil volatilized NH_3 was based on a work carried out by Tasca *et al*., (2011), performed in falcon tubes with a capacity of 15 mL, containing 10 mL of H_3PO_4 0.5 N with glycerin (1%) and two tapes of filter paper (1 x 8 cm) soaked in this solution to increase NH_3 contact surface with H_3PO_4. The falcon tubes were inserted by 2 cm into the soil, in the center of each experimental unit, where the pots were closed with a lid, which had six 2-mm holes to allow air circulation. Evaluations of NH_3 were performed daily from the first to the eighth day and from the 11^{th} to the 14^{th} day after fertilizer application, with monitored temperatures in the greenhouse (Figure 1).

The amount of volatilized NH_3 was determined daily by steam trapping in Kjeldahl semi-micro apparatus with distillation of a 10 mL aliquot, adding 10 mL of NaOH 10 M in each sample (Tedesco *et al*., 1995).

By the end of the evaluations, the daily and accumulated ammonia emissions were calculated, by discounting the value of the control for each fertilizer. The total accumulated from the fertilizers was expressed as percentage of applied N (equivalent to 140 kg ha^{-1}). Emission of accumulated NH_3 was adjusted by Mitscherlich equation, Eq.2 (Clay *et al*., 2012):

$$Y=A(1-e^{-bx}) \quad (1)$$

Where:

A and b - constants of the model, where A is the maximum theoretical value of accumulated ammonia and b is the adjustment coefficient;

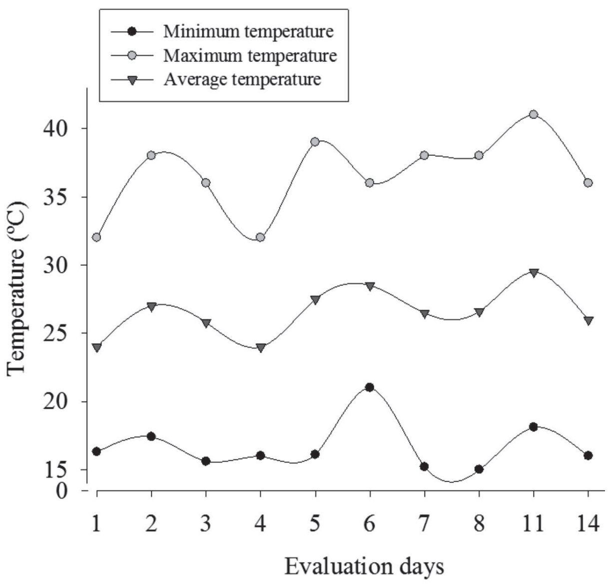

Figure 1: Minimum, maximum and average temperature during experiment period, under controlled conditions.

Y and x – dependent and independent variables, respectively.

Analysis of variance was performed by the F test and means of the experiments were compared by Tukey's test ($P < 0.05$). For the emissions of accumulated ammonia and percentage of lost N, the fertilizers and their modes of application were compared within the same pH; and each fertilizer with the same mode of application at different pH, both evaluating the soils separately. The statistical package used was SAS (2007).

RESULTS AND DISCUSSION

Treatments main effect on daily volatization of ammonia

The effects on the daily emissions of NH_3 observed in clayey soil occurred for the type of fertilizer (Figure 2A) on the 3^{rd}, 6^{th} and 7^{th} day of evaluation. For the application mode and pH, an effect was observed on the 3^{rd} and 6^{th} day after fertilizer application (Figure 2C; Figure 2E). In the sandy soil, daily emissions of NH_3 displayed responses to fertilizers on the 1^{st}, 2^{nd} and 8^{th} day (Figure 2B), while for the application mode, an effect was found on the 1^{st}, 2^{nd}, 5^{th} and 8^{th} day (Figure 2D). In the pH factor, the effects occurred on the 1^{st}, 3^{rd}, 4^{th}, 7^{th}, 11^{th} and 14^{th} (Figure 2) days.

The highest volatilizations were observed on the third day after fertilizer application (Figures 2A and Figure 2B), in both soils. At the peak of volatilization, the addition of SS differed from the other treatments in the clayey soil (Figure 2A), which can be attributed to the high initial concentration of ammoniacal N added into the soil, what is in agreement with a work carried out with SS (Misselbrook *et al*., 2002).

By adding urea, volatilization starts after enzymatic hydrolysis and ammoniacal N release. In the sandy soil, no difference was found between the fertilizers on the third day of evaluation, probably because of the soil structure, which may have favored nitrate leaching.

The use of DCD together with the SS in the clayey soil (Figure 2A) reduced the NH_3 emission when compared to the SS without DCD on the third day, while in the sandy soil, DCD had no effect. The higher presence of NH_4^+ in the soil with the use of DCD did not increase NH_3 emission because soils with a greater clay content have a lower tendency to lose N in the form of NH_3 due to their higher buffering capacity and the higher capacity of retaining ammonium.

For the mode of application of the N sources to the soil, the injection showed lower emission of NH_3 in relation to the surface application at the peak of volatilization in the clayey soil (Figure 2C). This reduction is due to the lower exposure of the manure to the air and to the higher N-ammoniacal retention in the soil particles (Dell *et al*., 2012). In the sandy soil, no difference in the volatilization of NH_3 was found between modes of application at the peak of emission (Figure 2D). The effect of temperature on volatilization of NH_3 may also have favored this loss. Tasca *et al*. (2011) found that the emissions occurring with the addition of urea in a Cambisol were 30% higher at 35 ºC than at 18 ºC. In this experiment, the peak of volatilization coincided with maximum temperature higher than 35 ºC (Figure 1), mainly when the fertilizers were applied on the surface.

Correcting soil pH (Figure 1E, Figure 2F) influenced the volatilization of NH_3 on both soils on the third

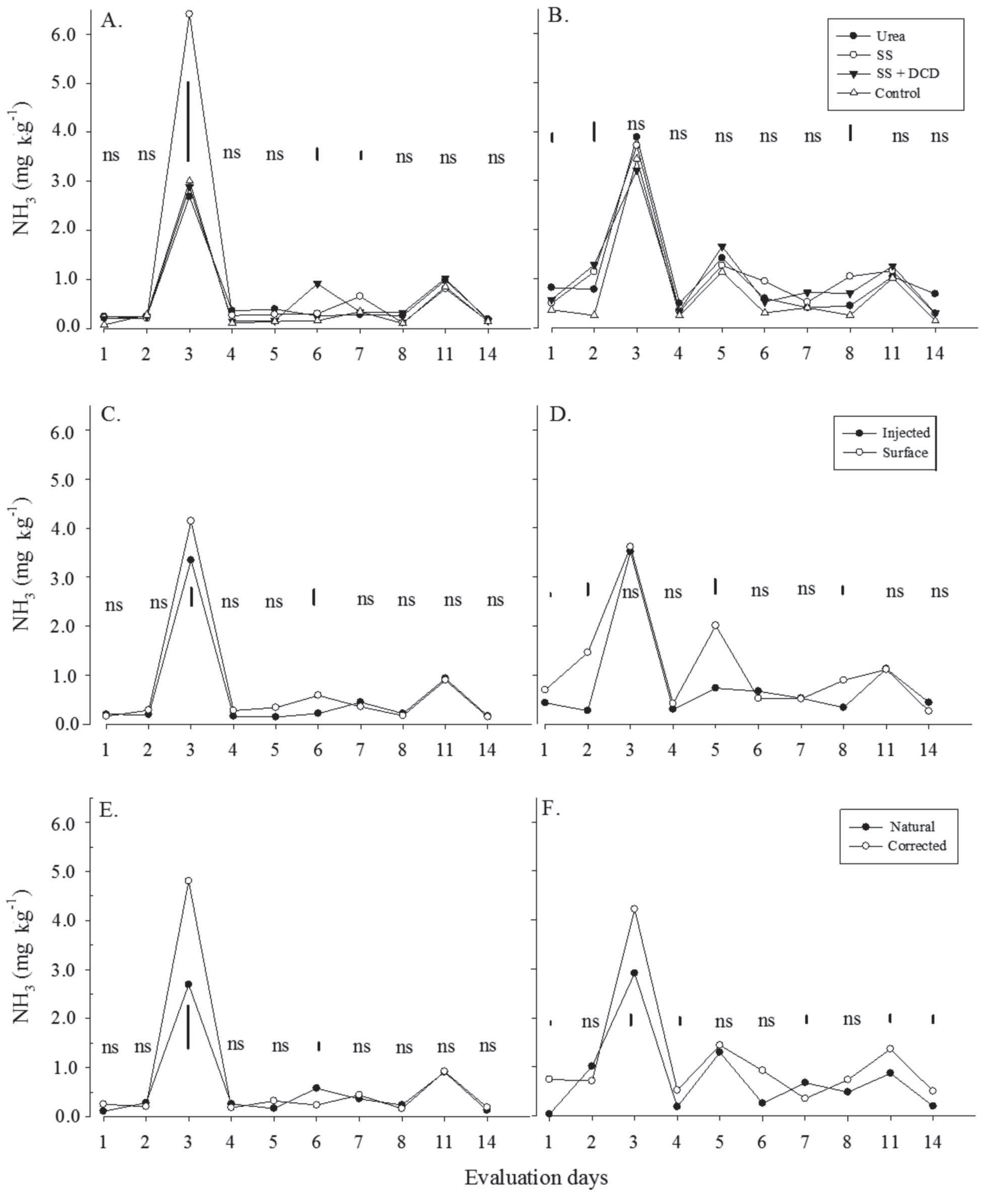

Figure 2: Main effect for daily ammonia volatilization from application of fertilizers (Urea, SS, SS+DCD, and Control), with two application modes (Injected and Surface), two pH conditions (Natural and Corrected) in a Rhodic Kandiudox (A, C, E) and Typic Hapludult (B, D, F). Vertical bars: represent the minimum significant difference by the Tukey's test ($p < 0.05$); ns: not significant. SS: swine slurry. DCD: Dicyandiamide.

evaluation day, when limed soil had higher emission. The absence of acid sites (H^+) prevents ammonia gas from returning to the mineral N (NH_4^+) form, which contributes to the intensification of emissions.

Observed and theoretical accumulated ammonia volatilization

By analyzing NH_3 theoretical maximum loss (Table 1), it can be observed that with the addition of SS in the clayey soil with corrected pH on the surface application, the emission would reach 21.7 mg kg^{-1}, indicating that on day 14, 92% of maximum volatilization would be reached. However, the greatest difference between the observed value and the theoretical maximum occurred in the treatment where SS + DCD was applied in the clayey soil at natural pH and with surface application, which represented an additional loss of 29.8%, indicating that on the 14th day, 70% of theoretical maximum volatilization would be reached.

In the sandy soil, accumulated theoretical losses that had the largest difference between the observed accumulated value and the theoretical (Table 1), occurred due to the application of SS (17.8 mg kg^{-1}) and SS + DCD (17.8 mg kg^{-1}) on the surface with adjusted pH, followed by SS injection with adjusted pH (15.4 mg kg^{-1}), where both indicate that 80%, 81% and 78% of the maximum volatilization would be reached on the 14th day, respectively.

Effect of interaction of treatments on accumulated ammonia volatilization

It is observed in the accumulated emissions of ammonia (Table 2) that in clayey soil at natural pH (4.8), the highest emission occurred in the SS + DCD on the surface (8.48 mg kg^{-1}), which was similar to that where SS (6.32 mg kg^{-1}) and urea (6.69 mg kg $^{-1}$) were added. The fertilizers injected in the clayey soil at natural pH presented the lowest accumulated NH_3 volatilization, which is equivalent to the addition of urea and SS on the surface. For the emissions that had occurred in the clayey soil under adjusted pH (6.0) the addition of SS to the surface showed the highest accumulated NH_3 emission (19.9 mg kg^{-1}), differing from the other treatments.

The highest emissions due to the addition of SS to the surface in the clayey soil at natural and corrected pH may be attributed to the high ammoniacal N content of the SS (4.2 kg m^{-3}), which promotes NH_3 volatilization, and to the surface application, which facilitates gas exchange. In addition, the acidity correction results in a lower amount of H^+ ions and there would be less transformation of NH_3 into NH_4^+.

The accumulated emission of NH_3 with addition of urea on surface of the clayey soil (Table 2) may be related to the ammonification of urea, which increases the pH of the soil in micro sites, due to the consumption of protons (H^+) and, consequently, increasing NH_3 emissions (Chen *et al*., 2013). Webb *et al*. (2014),

Table 1: Observed and theoretical accumulated ammonia (mg kg^{-1}), with addition of fertilizers (SS, SS + DCD, urea) applied in two conditions of pH (natural and corrected) and two modes of application (injected and surface), in a Rhodic Kandiudox and a Typic Hapludult soil

Treatment	Observed accumulated volatilization[1a]	Theoretical accumulated volatilization	Observed accumulated volatilization[1a]	Theoretical accumulated volatilization[1b]
	Rhodic Kandiudox			
	Natural pH		Corrected pH	
SS-Injected	4.46	$y=6.891*(1-e^{-0.081*x})$	7.10	$y=8.7743*(1-e^{-0.2063*})$
SS +DCD- Injected	5.11	$y=7.617*(1-e^{-0.085*x})$	6.17	$y=6.9437*(1-e^{0.1729*})$
Urea - Injected	3.70	$y=5.986*(1-e^{-0.071*x})$	6.31	$y=7.6653*(1-e^{0.1339*x})$
SS - Surface	6.32	$y=7.234*\ (1-e^{\ -0.168*x})$	19.8	$y=21.699*(1-e^{-0.265*x})$
SS +DCD - Surface	8.48	$y=12.096*\ (1-e^{\ 0.105*x})$	5.85	$y=6.653*(1-e^{0.159*x})$
Urea - Surface	6.69	$y=7.608*\ (1-e^{\ -0.183*x})$	7.07	$y=7.984*(1-e^{-0.172*x})$
	Typic Hapludult			
	Natural pH		Corrected pH	
SS - Injected	7.58	$y=8.377*(1-e^{-0.190*x})$	12.11	$y=15.452*(1-e^{-0.131*x})$
SS +DCD- Injected	6.75	$y=8.668*(1-e^{-0.121*x})$	8.53	$y=11.342*(1-e^{-0.111*x})$
Urea - Injected	7.35	$y=10.288*(1-e^{-0.103*x})$	11.77	$y=13.423*(1-e^{-0.132*x})$
SS - Surface	9.90	$y=10.803*(1-e^{-0.214*x})$	14.18	$y=17.844*(1-e^{-0.127*x})$
SS +DCD - Surface	12.72	$y=14.614*(1-e^{-0.172*x})$	14.47	$y=17.807*(1-e^{-0.178*x})$
Urea - Surface	12.72	$y=14.614*(1-e^{-0.172*x})$	15.56	$y=17.117*(1-e^{-0.154*x})$

SS: swine slurry; DCD: Dicyandiamide; [1a] Cumulative loss values discounted from the emissions of the control; [1b] Equation of accumulated ammonia loss adjusted by Mitscherlich's model.

injected animal manure into a clayey and sandy soil, and found a reduction in NH_3 emission in relation to surface application.

Effects of DCD on ammonia volatilization can be variable. Zaman & Blennerhassett (2010), mixed DCD with animal urine and observed an increase in NH_3 emissions; on the other hand, Pujol (2012), added DCD to SS and concluded that there was no increase in NH_3 emission in a sandy soil. Ni *et al*. (2014), applied DCD with urea on the surface of a sandy soil, and did not observed any increase in accumulated ammonia emissions.

By comparing the two pH conditions (Table 2) in the clayey soil, the pH correction resulted in the highest ammonia emissions in relation to the natural pH occurred, except for the application of SS + DCD on the surface (5.85 mg kg^{-1}).

In the emissions verified in the sandy soil (Table 2) under natural pH (4.2), no effect of DCD was found. The highest emissions occurred in the treatments with SS + DCD (12.72 mg kg^{-1}) and SS (9.90 mg kg^{-1}), both applied on the surface. Aita *et al*. (2014) studied the injection of SS + DCD in sandy soil and verified that the emissions of NH_3 were smaller, in relation to the superficial application. For the limed sandy soil (pH 6.8) all treatments had higher NH_3 emissions, compared to the natural pH, except for the injected treatments, where the lowest emission was observed in the SS + DCD treatment (8.53 mg kg^{-1}). Tasca *et al*. (2011), evaluating the volatilization of NH_3 with the addition of urea in Cambisols with corrected (6.0) and natural pH (5.5), concluded that volatilization of NH_3 increased in the limed soil.

The highest accumulated emissions observed with fertilizers applied on the surface are in accordance with Gonzatto *et al*. (2013), who by adding 60 m^3 ha^{-1} SS on the surface of an sandy soil, observed an increase in the volatilization of NH_3.

Effect of the interaction between treatments on the percentage of N lost by volatilization

The percentage of N lost by NH_3 volatilization (Table 3) in the clayey soil showed no difference between treatments with natural pH. A difference was found between the two pH conditions in the treatment with SS + DCD applied to the surface, where the largest loss of N (22.4%) occurred in the corrected pH.

In the sandy soil (Table 3) in natural pH, the highest percentage of lost N occurred in the SS + DCD applied on the surface (6.8%), equivalent to the SS with no DCD. In this same soil with corrected pH, the lowest N loss was observed in the injected SS + DCD, which is similar to the treatment with injected urea. Treatments under acid soil conditions showed lower N loss, except the SS + DCD surface treatment which was similar to the condition of corrected soil (Table 3).

Table 2: Volatilization of accumulated ammonia, with addition of fertilizers (Urea, SS, SS + DCD,) applied in two pH conditions (natural and corrected) and two modes of application (injected and surface), in a Rhodic Kandiudox and a Typic Hapludult soil

Treatment	Accumulated ammonia (mg kg^{-1})	Treatment	Accumulated ammonia (mg kg^{-1})	LSD (Fertilizer)	CV %
Rhodic Kandiudox with natural pH		Rhodic Kandiudox with adjusted pH			
SS - Injected	4.46 Ab	SS - Injected	7.10 Ab	4.92	17.2
SS +DCD - Injected	5.11 Ab	SS +DCD - Injected	6.17 Ab	1.42	11.1
Urea - Injected	3.70 Bb	Urea - Injected	6.31 Ab	1.24	10.9
SS - Surface	6.32 Bab	SS - Surface	19.9 Aa	8.42	18.2
SS +DCD - Surface	8.48 Aa	SS +DCD - Surface	5.85 Bb	1.74	10.8
Urea - Surface	6.69 Aab	Urea - Surface	7.07 Ab	3.81	18.4
LSD (Mode of application)	3.01	LSD (Mode of application)	7.31		
CV %	18.9	CV %	18.5		
Typic Hapludult with natural pH		Typic Hapludult com adjusted pH			
SS - Injected	7.58 Bb	SS - Injected	12.11 Aab	4.51	19.2
SS +DCD – Injected	6.75 Ab	SS +DCD - Injected	8.53 Ab	2.57	14.8
Urea - Injected	7.35 Bb	Urea - Injected	11.77 Aab	3.51	16.2
SS - Surface	9.90 Bab	SS - Surface	14.18 Aa	2.13	7.8
SS +DCD- Surface	12.72 Aa	SS +Inhibitor - Surface	14.47 Aa	4.41	14.3
Urea - Surface	7.83 Bb	Urea - Surface	15.56 Aa	2.65	9.6
LSD (Mode of application)	4.1	LSD (Mode of application)	4.1		
CV %	17.1	CV %	11.8		

LSD: least significant difference; CV: coefficient of variation; Upper case letters compare fertilizers applied in the same soil in different pH; Lower case letters compare fertilizers with mode of application in the same soil at equal pH. Tukey ($p < 0.05$).

Table 3: Percentage of nitrogen loss in relation to the applied nitrogen from fertilizers (Urea, SS, SS + DCD) applied in two pH conditions (natural and corrected) and two modes of application (injected and surface), in a Rhodic Kandiudox and a Typic Hapludult soil

Treatment	Accumulated ammonia (%)	Treatment	Accumulated ammonia (%)	LSD (Fertilizer)
Rhodic Kandiudox with natural pH		Rhodic Kandiudox with adjusted pH		
SS - Injected	1.5 Aa	SS - Injected	4.23 Ab	7.58
SS +DCD - Injected	2.4 Aa	SS +DCD - Injected	1.78 Ab	2.03
Urea - Injected	0.4 Aa	Urea - Injected	2.00 Ab	1.76
SS - Surface	1.5 Ba	SS - Surface	22.4 Aa	12.42
SS +DCD - Surface	4.6 Aa	SS +DCD - Surface	2.66 Ab	2.57
Urea - Surface	2.0 Aa	Urea - Surface	4.1 Aa	4.58
LSD (Mode of application)	4.31	LSD (Mode of application)	10.07	
Typic Hapludult with natural pH		Typic Hapludult with adjusted pH		
SS - Injected	2.3 Bab	SS - Injected	8.5 Aa	4.23
SS +DCD - Injected	1.2 Ab	DLS+DCD - Injected	2.5 Ab	3.72
Urea - Injected	2.0 Bab	Urea - Injected	7.1 Aab	5.01
SS - Surface	3.7 Bab	SS - Surface	8.0 Aa	3.06
SS +DCD- Surface	6.8 Aa	SS +Inhibitor - Surface	8.4 Aa	4.17
Urea - Surface	2.1 Bab	Urea - Surface	10.1 Aa	3.78
LSD (Mode of application)	4.95	LSD (Mode of application)	4.82	

LSD: least significant difference; Upper case letters compare fertilizers applied in the same soil in different pH; Lower case letters compare fertilizers with mode of application in the same soil at equal pH. Tukey ($p < 0.05$).

CONCLUSIONS

Injection of fertilizers reduced the cumulative emission of ammonia in relation to the surface application in both soils.

The use of the nitrification inhibitor did not influence volatilization of ammonia in both soils.

The highest percentage of nitrogen lost by ammonia volatilization occurred in the surface application under conditions of corrected pH in the clayey soil.

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