Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Lime and Fertilizer

Addition of Urease Inhibitor Has No Effect on Ammonia Volatilization Following Soil Application of Poultry Litter or Organomineral Fertilizer, Unlike Urea

Késia Silva Lourenço[(1)], Paulo Roberto Ernani[(2)], Juliano Corulli Corrêa[(3)], Sulian Junkes Dal Molin[(2)] and Lucas Silva Lourenço[(2)]

[(1)] Instituto Agronômico de Campinas, Programa de Pós-graduação, Campinas, São Paulo, Brasil.
[(2)] Universidade do Estado de Santa Catarina, Departamento de Solos, Lages, Santa Catarina, Brasil.
[(3)] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Suínos e Aves, Concórdia, Santa Catarina, Brasil.

*** Corresponding author:**
E-mail: paulorobertoernani@gmail.com

Received: January 21, 2015
Approved: September 25, 2015

How to cite: Lourenço KS, Ernani PR, Corrêa JC, Dal Molin SJ, Lourenço LS. Addition of Urease Inhibitor Has No Effect on Ammonia Volatilization Following Soil Application of Poultry Litter or Organomineral Fertilizer, Unlike Urea. Rev Bras Cienc Solo. 2016;40:e0150031.

ABSTRACT: Quantification of ammonia volatilization after addition of animal residues and nitrogen (N) mineral fertilizers to the soil is important for N management in fertilization programs. The objective of this study was to evaluate the effect of adding a urease inhibitor to N fertilizers to minimize ammonia losses following soil application. The experiment was carried out in a laboratory with samples of a Brazilian Oxisol containing 790 g kg^{-1} clay and 23 g kg^{-1} organic matter. Treatments consisted of addition of poultry litter (PL), organic mineral fertilizer (OMF) and urea to the soil, with and without the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT), plus a control with no fertilizer. We applied the fertilizers over the soil surface, with no soil incorporation, at a rate of 200 mg kg^{-1} N. Experimental units consisted of PVC tubes with a diameter of 0.15 m, containing 1.0 kg of soil (dry basis). Ammonia volatilization was measured for 56 days following fertilizer application to the soil using sponge discs impregnated with phosphoric acid and glycerin, which were fitted inside the tubes 0.15 m above the soil surface. Ammonia volatilization peaks varied according to the fertilizer, and most of them occurred in the first 15 days following application to the soil. Total ammonia volatilized from the soil treated with PL or OMF had no influence on the urease inhibitor, probably because the losses were small, attaining a maximum of 2.5 and 9 % of the total N applied, respectively. In the treatment that received urea, NBPT delayed the peak of volatilization by three weeks and decreased the loss of ammonia from 22 to 9 % of the N applied. Use of urease inhibitor does not always decrease ammonia volatilization, especially when mixed with fertilizers in which urea is not the only source of N.

Keywords: animal waste, nitrogen fertilizers, surface fertilization.

INTRODUCTION

Increasing the efficiency of nitrogen (N) use is a permanent goal that contributes to decreasing crop production costs and the risks of environmental pollution. Urea is the N fertilizer most used in Brazil and the main concern regarding this fertilizer is ammonia volatilization, which occurs when the fertilizer is surface applied. Recent studies show that adding urease inhibitor to urea decreases ammonia volatilization in the days immediately following soil application (Cantarella et al., 2008; Tasca et al., 2011).

The soil seems to be to best place to distribute poultry waste because, in addition to supplying plant nutrients, this technique avoids environmental pollution. Due to the high costs of transportation, the use of poultry litter is limited to croplands near the production sites. Since these wastes are generally not incorporated into the soil and part of the N in this animal residue is in the form of ammonium or urea (Kpomblekou-a, 2006), ammonia may be lost to the atmosphere, as occurs when urea is surface applied.

After evaluating many studies, Sommer and Hutchings (2001) found that poultry litter, the waste generated from confined bird meat production, has an average of 27 g kg^{-1} total N, in which 6.5 g kg^{-1} are in the ammonium form (NH_4^+-N) and 7.54 g kg^{-1} are in the uric acid form, which is later transformed to urea. Thus, these soluble forms of N in poultry litter are susceptible to loss as ammonia from storage piles or from the soil surface after application without incorporation.

The magnitude of N losses by volatilization of ammonia after addition of animal residues or chemical fertilizers to the soil is a complex process that depends on several factors related to climate, to edaphic conditions, and to soil and residue characteristics (Sommer and Hutchings, 2001; Tasca et al., 2011). Sharpe et al. (2004) measured ammonia volatilization after addition of poultry litter to the soil and found losses up to 3.3 and 24 % of the total N applied in the winter and summer, respectively, where the highest values occurred in periods of high temperatures, drought, and high wind. Following urea application, ammonia volatilization may range from negligible values (Viero et al., 2014) up to more than 40 % of the total N applied (Oliveira et al., 2014).

The use of urease inhibitors temporarily decreases hydrolysis of urea, giving more time for N to penetrate into the soil (Christianson et al., 1990). The most used urease inhibitor is N-(n-butyl) thiophosphoric triamide (NBPT), which has decreased ammonia volatilization up to 78 % in field conditions, depending on climate conditions (Cantarella et al., 2008). In addition to its effects on urea, this compound was also effective in decreasing ammonia volatilization up to 69 % from poultry litter (Singh et al., 2009) and swine manure in confined systems (Parker et al., 2005).

Recently in the state of Santa Catarina mineral fertilizers have been added to poultry litter to increase the concentration of nutrients in the blend, allowing, thus, its transportation to longer distances from the production sites. The efficiency of the N present in this organomineral fertilizer (OMF) is partly dependent on ammonia volatilization, as occurs to urea or poultry litter.

Based on the hypothesis that addition of urease inhibitor to organic and OMF fertilizers is not as efficient as when it is added to urea in delaying the peak of ammonia volatilization, this study was carried out to assess the effect of mixing a commercial urease inhibitor with three nitrogen fertilizers on ammonia volatilization following soil addition.

MATERIALS AND METHODS

The experiment was carried out in a laboratory in Lages, Santa Catarina State, in southern Brazil, from September until November 2011, without controlled temperature. Local temperature values are shown on figure 1. The predominant climate is Cfb, according to the Köppen classification system.

The soil used was an Oxisol, or *Nitossolo Vermelho Distroférrico* (Santos et al., 2013), collected from the 0.00-0.30 m depth of an area with native grasses that had never been cropped or fertilized before. The soil had 790 g kg^{-1} clay, 23 g kg^{-1} organic matter (OM), 6.7 mg kg^{-1} P, 64 mg kg^{-1} K, and pH 4.6. After that, 6.0 g kg^{-1} of dolomitic limestone were applied to raise the soil pH to 6.5, and then the samples were incubated for 6 days.

Treatments consisted of three N fertilizers: poultry litter (PL), organomineral fertilizer (OMF), and urea, with or without the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT), plus a control with no fertilizers. The PL was collected in a confined poultry meat production system, where six lots of birds were raised over the bedding. Before the beginning of the experiment, PL samples remained in storage for three months. The OMF was produced by mixing PL and mineral fertilizers. The PL samples were initially pelletized at temperatures from 35-40 °C during the process, followed by mixing or not with the urease inhibitor (NBPT). The NBPT used with all three fertilizers was Agrotain® at a rate of 4.0 L for each ton of fertilizer.

All fertilizers were surface applied, with no incorporation, at a rate of 200 mg kg^{-1} N. The experimental units were PVC tubes of 0.15 m diameter, filled with 1.0 kg of dry soil. We maintained soil moisture at field capacity throughout the time of the experiment. After each ammonia evaluation, we weighed the experimental units, and, when necessary, added distilled water.

The PL had the following composition: total N 20.0 g kg^{-1}; soluble N 4.0 g kg^{-1}; NH_4^+-N 1.5 g kg^{-1}; NO_3^--N 0.0 g kg^{-1}; urea-N 1.0 g kg^{-1}; water 810 g kg^{-1}; and C:N ratio 13:1. The composition of the OMF was: total N 65 g kg^{-1}; soluble N 42.0 g kg^{-1}; NH_4^+-N 34.5 g kg^{-1}, NO_3^--N 4.7 g kg^{-1}, urea-N 21.5 g kg^{-1}. The urea had 450 g kg^{-1} N.

The ammonia collecting chambers were PVC tubes of 0.15 m diameter and 0.30 m length, placed on top of the experimental units. Ammonia was trapped through use of commercial sponge discs of 2.5 cm height and density of 24 kg m^{-3} inside the PVC tubes,

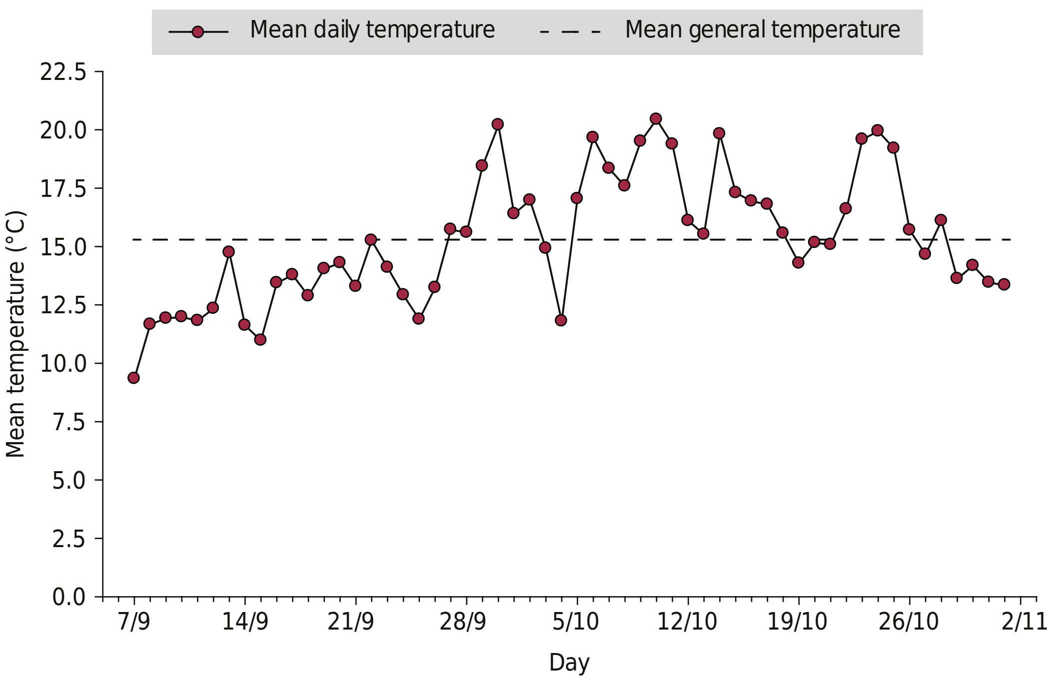

Figure 1. Mean daily temperature in Lages, southern of Brazil, during the experimental period, from 07 July 2011 to 11 January 2012.

placed 0.15 m above the soil surface. Another sponge disc was inserted at the top of the PVC tube to avoid contamination of ammonia from the atmosphere. Before use, the sponge was washed with water, 0.73 mol L^{-1} phosphoric acid, and then distilled water, and, finally, air dried. After that, each disc received 20 mL of 0.73 mol L^{-1} phosphoric acid containing 30 % glycerin.

We replaced the discs 2, 4, 6, 8, 16, 24, 32, 40, 48, and 56 days after addition of the fertilizers to the soil. The replaced discs were stored in sealed plastic bags and kept in the refrigerator until analysis. The discs containing ammonium phosphates received 100 mL of 1.0 mol L^{-1} KCl and remained 12 h in equilibrium; they were then manually squeezed to expel the solution. Ammonia was quantified by steam distillation (Tedesco et al., 1995). At the end of the experiment, the soil from each unit was homogenized and samples were collected to determine the amounts of ammonium and nitrate remaining in the soil. These forms of N were extracted from the soil with 1.0 mol L^{-1} KCl and determined according to Tedesco et al. (1995).

A completely randomized experimental design was used, with four replications. Statistical analysis of data was made through Analysis of Variance using the F-test ($p<0.05$) from SAS (2008), followed by comparison of means by the Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

Amount of ammonia volatilized

Conventional urea fertilizer promoted the highest ammonia volatilization. In addition, urea was the only fertilizer in which the urease inhibitor was effective (Figure 2). In addition to delaying the peak of volatilization by approximately 16 days, adding NBPT to urea also led to a 36 % decrease in the total ammonia lost in relation to urea without the urease inhibitor. At the end of the 56-day experimental period, ammonia losses accounted for 22 and 14 % of the total N applied from treatments with conventional urea and with urea + NBPT, respectively. Tasca et al. (2011) also detected that the addition of urease inhibitor to urea delayed ammonia volatilization, with no effect on the total ammonia lost. Ammonia losses following addition of urea to the soil surface occur because hydrolysis of the urea molecule increases the soil pH near the fertilizer granules (Ernani et al., 2001), where part of the ammonium transforms into ammonia. The urea molecule is stable in aqueous media, and its

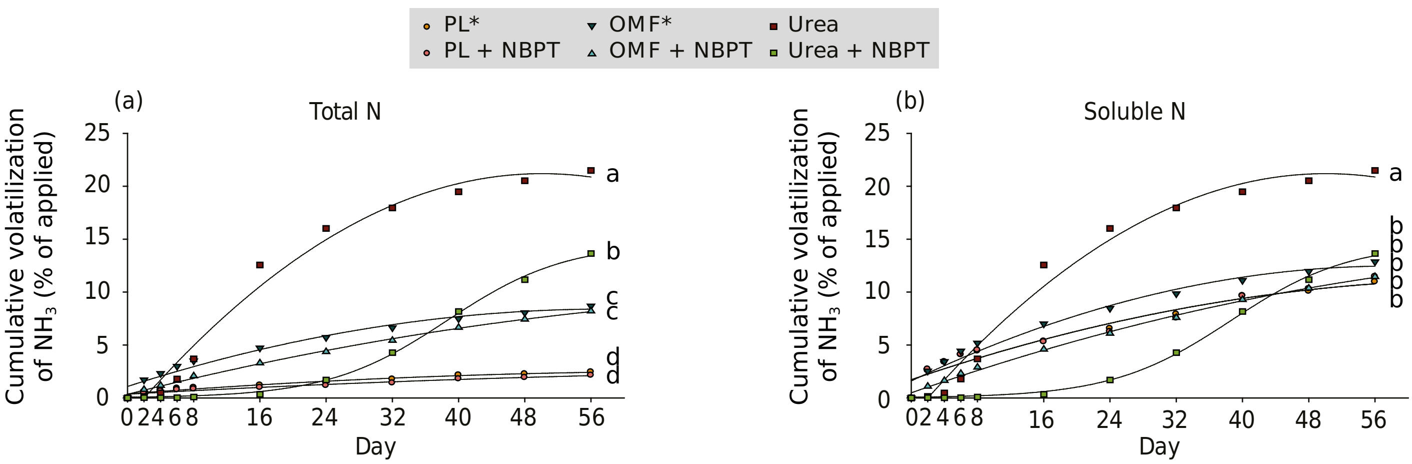

Figure 2. Cumulative volatilization of ammonia following application of 200 mg kg^{-1} N on the soil surface from nitrogen fertilizers, in the presence or absence of N-(n-butyl) thiophosphoric triamide (NBPT), relatively to the amount of total N (a) or soluble N applied (b). Values were subtracted from those in the treatment that did not receive N fertilizer (control). Treatments followed by the same lowercase letters do not differ by the Tukey test ($p<0.05$) on cumulative losses of ammonia at 56 days after soil application. PL*: Poultry litter; OMF*: organomineral fertilizer.

hydrolysis depends on the catalysis promoted by the urease. NBPT is a molecule that inhibits urease activity, thus delaying hydrolysis of the urea molecule.

The amount of ammonia volatilized from the addition of urea to the soil surface in our experiment is in the range found by most studies, which varies from 5 to 25 % (Cantarella et al., 2008; Viero et al., 2014). In extreme conditions, however, these losses may be higher than 40 % (Oliveira et al., 2014). Addition of NBPT to urea has usually been effective in decreasing ammonia losses (Cantarella et al., 2008; Viero et al., 2014), but not always (Tasca et al., 2011; Oliveira et al., 2014).

Ammonia losses from addition of poultry litter to the soil were small, regardless of the presence or absence of the urease inhibitor (NBPT) (Figure 2). The cumulative ammonia volatilized from the treatments with poultry litter accounted for a maximum of 2.4 % of the N applied; in relation to total soluble N (20 %), ammonia losses accounted for 11.5 %. Probably due to these small losses of ammonia, addition of NBPT to poultry litter had no effect on either the total ammonia emitted or delay in the volatilization peak. The small amount of ammonia volatilized from the treatment with poultry litter is probably due to previous storage of this waste for 90 days before soil application. In addition, high temperature was used in the granulation process. These phenomena promoted losses of ammonia from some N fractions (López-Mosquera et al., 2008), including uric acid, urea, and ammonium (Thomsen, 2004; Bolan et al., 2010; Miola et al., 2014). Consequently, less ammonia volatilization occurred following addition of poultry litter to the soil, due to the presence of more stable organic N fractions in the material (Brinson et al., 1994; López-Mosquera et al., 2008).

When poultry litter was not dried after excretion in the poultry facilities, 20 % of its total N was lost within the first 4.5 h after soil application (Miola et al., 2014). In addition to wide variability, poultry litter lots from meat production confinement facilities have an average of 60 % of total N in the organic form, 30 % as ammonium, and 10 % as nitrate and amidic forms (Kpomblekou-a, 2006). Thus, as occurred for ammonia volatilization from urea, the absence of air flow inside the volatilization chambers (Miles et al, 2012) and the low temperature during the experimental period (Tasca et al., 2011) certainly decreased ammonia emission from the treatment with poultry litter.

Variations in ammonia volatilization according to the destination of the poultry litter before being applied to the soil: with fresh poultry litter, 17 to 31 % of the N applied was lost, which decreased to 0.2 % when the material was previously stored (Brinson et al., 1994). This was probably due to a decrease in the readily-available N fractions (López-Mosquera et al., 2008). The storage of poultry litter after being removed from production facilities is a common practice among poultry producers in Brazil since the sale price of this waste is higher at the time of crop sowing or orchard regrowth.

The amount of ammonia volatilized from the soil treated with OMF was intermediate compared to the gas emissions from soils treated with urea or poultry litter (Figure 3). This occurs because OMF is produced from a mixture of mineral fertilizer and PL. Averaged across treatments with and without NBPT, ammonia emission from the OMF was 8.4 % of the total N applied and 12 % of the soluble N contained in the fertilizer. The presence or absence of urease inhibitor also did not affect the volatilization of ammonia from the treatment with OMF.

The use of a closed, static system for trapping ammonia may also have contributed to underestimation of ammonia losses in our study. Lara Cabezas and Trivelin (1990) applied ^{15}N-labelled urea to the soil and measured ammonia volatilization using a semi-open static collector for 37 days. They found that with the trapping chamber there was a decrease of 29 % in ammonia volatilization in relation to the treatment with no chamber. Thus, under

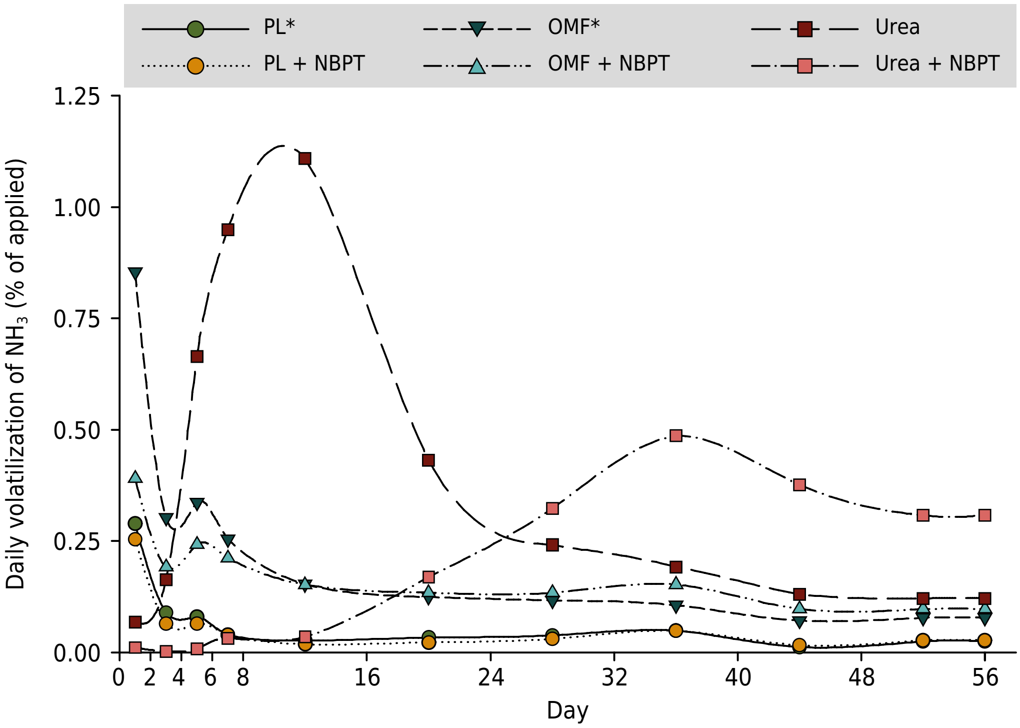

Figure 3. Daily volatilization of ammonia in relation to the total N applied, following application of 200 mg kg^{-1} N at the soil surface from nitrogen fertilizers, in the presence or absence of N-(n-butyl) thiophosphoric triamide (NBPT). Values were subtracted from those volatilized from the treatment that did not receive N (control). PL*: Poultry litter; OMF*: organomineral fertilizer.

field conditions, ammonia losses may be even higher than in the laboratory, where the conditions for volatilizations are less favorable, mainly due to absence of wind (Sommer and Hutchings, 2001; Miles et al., 2012) and changes in luminosity and processes of soil moistening and drying. Araújo et al. (2009) found that ammonia volatilization in the laboratory was 57 % lower than in the field.

Peak of volatilization

The peak and daily rates of volatilization varied according to the fertilizer used, but were affected by the presence of urease inhibitor only on the treatment with urea (Figure 3). The highest daily losses of ammonia occurred from the treatment that received N exclusively as urea, and were concentrated between 8 and 16 days after application to the soil. During this period, it was 93 % higher than losses occurring from the other fertilizers. In this period, 2.22 mg N per experimental unit were lost per day, which corresponds to 1.1 % per day of the total N applied to the soil. In the treatment with urea + NBPT, the highest rates were of 0.5 % per day of the N applied, and occurred between 32 and 40 days after soil addition, that is, a delay of approximately three weeks compared to the treatment with conventional urea alone.

The peak of ammonia volatilization from the soil treated with conventional urea alone occurred a week later than what has normally been observed (Sangoi et al., 2003; Sharpe et al., 2004; Tasca et al., 2011; Oliveira et al., 2014). The delay in this peak in our study is probably due to the low temperatures during the experimental period, a mean of 15 °C (Figure 1), and this may have negatively affected urease activity and urea hydrolysis (Clay et al., 1990). Tasca et al. (2011) found that ammonia volatilization following urea application was 30 % higher at a temperature of 35 °C than at 18 °C. Viero et al. (2014) observed ammonia losses following urea application of approximately 5 and 15 % of the N applied for winter and summer crops, respectively. O'Connor and Hendrickson (1987) observed that hydrolysis of urea was completed after 1, 4, 6, 7, and 8 days after soil application at temperatures of 35, 25, 15, 10, and 5 °C, respectively; at temperature of 35 °C, 70 % of the N applied was lost in seven days.

Unlike the pattern that occurred with urea, the highest losses of ammonia from treatments with OMF or PL were on the days immediately following soil application, regardless of the presence or absence of urease inhibitor. In addition, daily losses in relation to the N applied were also lower: 0.62 % per day for OMF and 0.3 % per day for PL (Figure 3). The volatilization of ammonia from the soil treated with poultry litter was less than that observed in other studies in which animal waste was used (Miola et al., 2014). This was probably due to the storage of our poultry waste before the beginning of the experiment, as well as the granulation process and low N content, as previously discussed. However, as normally occurs following soil application of urea (Sangoi et al., 2003) or animal wastes (Sommer and Hutchings, 2001; Gonzatto et al., 2013; Miola et al., 2014), there was volatilization in the days immediately after application to the soil, and this is accelerated by an increase in soil pH promoted by these materials (Gonzatto et al., 2013).

Nitrogen in the soil

The content of mineral N remaining in the soil at the end of the study was high in treatments with urea and very low in those with PL (Figure 4). In the treatment that received urea + urease inhibitor, 84 % of the N applied remained in the soil in mineral forms, after subtracting the value from the control. After that comes the treatment with conventional urea, with 70 %, and then OMF, with 59 %. In the treatments with PL (with or without NBPT), the mineral N in the soil accounted for 8 % of the amount applied, with no effect from the NBPT, similar to that which occurred for OMF.

In the treatments with urea and urea + NBPT, we recovered 92 and 98 % of the N applied, respectively, when we consider the sum of volatilization and N remaining in the soil. In OMF, the recovery of N was 68 %, whereas in PL, it was 10.5 %, and in these fertilizers there was no effect of NBPT on both forms of N, volatilized or remained in the soil. These two fertilizers had most of N in the organic forms, which take some time to go to the soil solution.

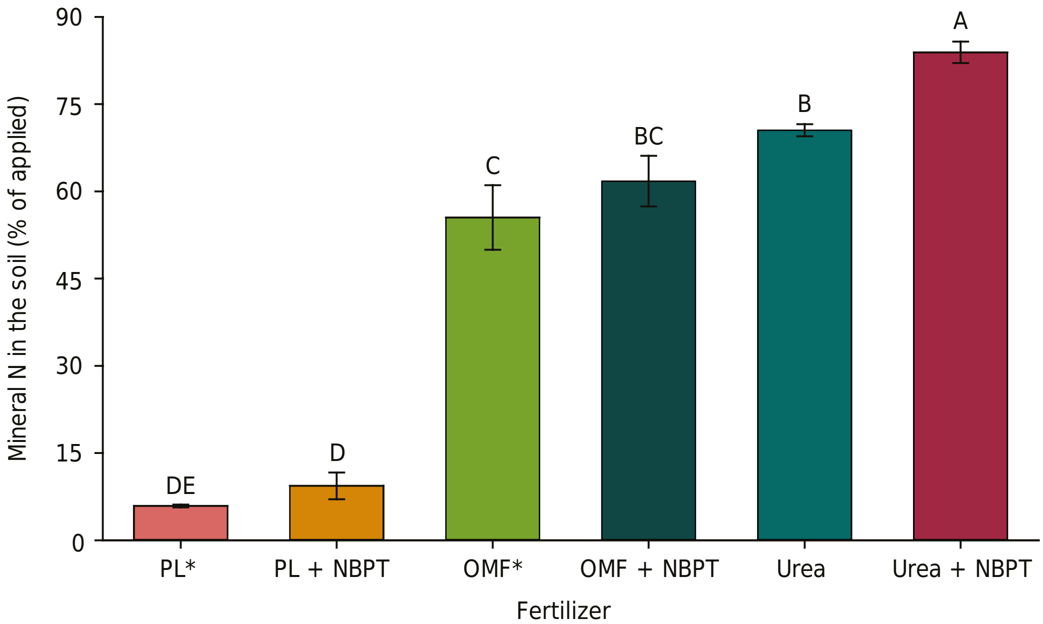

Figure 4. Percentage of mineral N (NH_4^+ + NO_3^-) in the soil in relation to the total nitrogen applied (200 mg kg^{-1} N) at 56 days after fertilizer application in the presence or absence of N-(n-butyl) thiophosphoric triamide (NBPT). Uppercase letters compare NH_4^+ values in the soil. Treatments followed by the same letter do not differ by the Tukey test ($p<0.05$). Bars in the columns indicate the average test error. PL*: Poultry litter; OMF*: organomineral fertilizer.

CONCLUSIONS

Addition of urease inhibitor to pelletized poultry litter or to organomineral fertilizer did not decrease ammonia volatilization after application of these fertilizers to the soil surface. With urea, however, the peak of ammonia emission occurred later and the total amount of ammonia lost decreased in the presence of NBPT.

The use of urease inhibitor does not always decrease ammonia volatilization, especially when urea it is not the only compound in the fertilizer.

Ammonia loss from addition of poultry litter to the soil was small, probably due to the previous storage of this waste before adding it to the soil.

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