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NBPT (urease inhibitor) in the dynamics of ammonia volatilization

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ABSTRACT: The duality in nitrogen fertilization is central to environmental impacts and productivity. Therefore, technologies like NBPT gain prominence, as it acts to inhibit the urease by slowing it down and decreasing the volatilization of the ammonia. Thus, the objective was to reduce the doses of the agricultural additive Uremax NBPT 500® (Uremax) and to evaluate the urease activity in the dynamics of nitrogen volatilization. It has been hypothesized that increasing doses of Uremax do not alter NH_3 losses but affect the dynamics of the process. For this, Red Latosol cultivated with *Brachiaria decunbens* was collected and under this was put nitrogen: urea; Urea with 20, 15 and 10% of Uremax; Two controls (nitrogenated from the market containing NBPT) and the control. Ammonia losses were quantified for 11 days, forming the split plot of the factorial in a completely randomized design with four replicates. For the final volatilization the treatments corresponded to the nitrogenous ones, with the same design and number of repetitions. The volatilization of the ammonia from the conventional urea is high, starting on the second day (2,765 mg) and the use of the inhibitor reduced the volatilization peak in up to four days. Doses of 10 to 20% of Uremax resulted in the same reduction of daily volatilization as commercial products. Urea with Uremax decreased the volatilization by approximately 75% after 11 days. Even with particularities over time, doses of Uremax from 10% applied in conventional urea also reduced the volatilization of ammonia, remaining stable in 6 mg.

Key words: nitrogen fertilization; Nitrogen, Oxygen [N- (n-butyl) phosphoric triamide]; N- (n-butyl) triamide thiophosphate; Urea

NBPT (inibidor de uréase) na dinâmica da volatilização da amônia

RESUMO: A dualidade na fertilização nitrogenada cerne nos impactos ambientais e na produtividade. Portanto, tecnologias como NBPT ganham destaque, pois atua inibindo a urease desacelerando-a e diminuindo a volatilização da amônia. Deste modo, o com objetivo reduzir as doses do aditivo agrícola Uremax NBPT 500® e avaliar a atividade urease na dinâmica de volatilização do nitrogênio; estabeleceu-se a hipótese de que doses crescentes do Uremax NBPT 500® não alteram as perdas de NH_3, mas afeta a dinâmica do processo. Para tanto, coletou-se Latossolo vermelho cultivado com Braquiária decunbens e sob este foi posto nitrogenados: ureia; ureia com 20, 15 e 10 de Uremax NBPT 500®; dois controles (nitrogenados do mercado contendo NBPT) e a testemunha. As perdas de amônia foram quantificadas por 11 dias, formando-se as subparcelas do fatorial em delineamento inteiramente casualizado com quatro repetições. Para a volatilização final os tratamentos corresponderam os nitrogenados, com o mesmo delineamento e número de repetições. A volatilização da amônia da ureia convencional é elevada, iniciando-se no segundo dia (2,765 mg NH_3) e o uso do inibidor reduziu o pico de volatilização em até quatro dias. As doses de 10 a 20% de Uremax NBPT 500 resultaram na mesma redução de volatilização diária que os produtos comerciais. A ureia com Uremax NBPT 500® diminuiu a volatilizaçao em aproximadamente 75% após 11 dias. Mesmo com particularidades ao longo do tempo, doses de Uremax NBPT 500® a partir de 10% aplicadas na ureia convencional reduziram igualmente a volatilização da amônia, permanecendo estáveis em 6 mg NH_3.

Palavras-chave: fertilização nitrogenada; NBPT; Nitrogênio; oxigênio [N-(n-butil) fosfórico triamide]; tiofosfato de N-(n-butil) triamida; Ureia

Introduction

Nitrogen compounds contribute to environmental impacts and from another perspective, establish an increase of CO_2 fixation and, consequently, promote higher productivity. With this dialectic view, technologies that maximize efficiency are gaining prominence, especially those related to the delay of volatilization (Fernandes et al., 2014). Among the nitrogen fertilizers, urea is the most used (Fernandes et al., 2014), as aggravating this fertilizer is hydrolyzed by urease when applied to soil, forming ammonia carbonate, which then deploys into NH_3, CO_2 and water. NH_3 reacts with H^+ resulting in NH_4^+. The losses of NH_3 in this process reaches 70% (Cantarella, 2007). Factors that interfere with this process include moisture, temperature, organic carbon and soil pH, wind speed and management techniques.

In general, the enzyme urease is extracellularly produced by bacteria, actinomycetes and fungi of the soil or, still, originated from organic residues. The most important commercial and practical urease inhibitor is NBPT (N-(n-butyl) triamide thiophosphate) that has solubility and diffusivity similar to that of urea (Guimarães et al., 2016). The NBPT decomposes within a few hours after application and is converted to its analogue [N- (n-butyl) phosphoric triamide] to then associate with the enzyme and have the inhibitory effect. The molecule acts by inhibiting the urease by occupying the active site, causing deceleration (Christianson et al., 1990; Watson, 2000; Cantarella, 2007; Cantarella et al., 2008). This delay in hydrolysis reduces the concentration of NH_3 on the soil surface and increases the possibility of rain incorporation (Rawluk et al., 2001). Therefore, this technology is feasible for no-tillage systems and minimum, where application of the urea is made on the soil (Espindula et al., 2014) and for the conventional one, due to the technique to enable the gradual release of nitrogen (Espindula et al., 2014). In both cases, the technology allows fertilization before ideal conditions, without significant losses of nitrogen.

In Brazil, the recommendations of the NBPT are 530 mg kg-1 (0.053%) (Cantarella, 2007), but the market concentration is 20%. Therefore, research on NBPT is necessary to evaluate the efficiency at lower concentrations, given the high value. Therefore, with the objective of reducing the dose of the agricultural additive Uremax NBPT 500® and evaluating the urease activity in the dynamics of volatilization, it has been hypothesized that increasing doses of Uremax NBPT 500® do not alter NH_3 losses but affect the dynamics of the process.

Materials and Methods

In an area of Red Latosol under cultivation *Brachiaria decunbens* for five years, soil samples were collected for physical and chemical characterization (Table 1). The soil was collected at a depth of 0 - 0.2 m, its preparation being restricted to air drying, to maintain the biological properties, sieving in the mesh of 16 mesh of opening and homogenization. The area used whose pasture was installed at the Capim Branco Experimental Farm of the Federal University of Uberlândia, Uberlândia-MG city (18° 53’19 “S, longitude 48° 20’57” W) with an average altitude of 250 meters and an annual average rainfall of 1250 mm. The climate of the region according to the climatic classification of Koppen-Geiger is Aw, tropical with dry winter season. This soil was chosen because it had adequate pH for cultivation, low phosphorus, adequate bases (K, Ca and Mg), very low sulfur, absence of aluminum, organic matter content and average cation exchange capacity (T) and saturation by base suitable for cultivation of most crops (Table 1). The soil texture was classified as medium sensu Santos et al. (2013), with clay content close to 24% (Table 1).

Of the soil, 400 grams were poured into a vessel, which represented the experimental unit. This material was leveled and was subsequently added water up to 70% of field capacity, which was maintained throughout the experiment. The water was placed in the vessels homogeneously by dripping with the aid of a pissette (93.4 grams of water for the 400 grams of soil). Then the pots rested for three days for percolation of the water and uniform wetting of the soil. Subsequently, 0.224 g of nitrogenous compounds were added to this soil, the composites being: T1- commercial urea; T2-urea with Uremax NBPT 500® diluted 4: 6 (20% NBPT); T3-urea with Uremax NBPT 500® diluted 3: 7 (15% NBPT); T4-urea with Uremax NBPT 500® diluted 2: 8 (10%

Table 1. Chemical and physical characterization of the Oxisol under cultivation of Brachiaria decunbens to a depth of 0-0,20 m.

pH_{H_2O} (1: 2.5)	P meh-1	K^+	$^{2-}S\text{-}SO_4$		Na^+	Ca^+	Mg^+	Al^{3+}	H + Al	V	m
	mg dm^{-3}				cmol$_c$ dm^{-3}					%	
6.0	1.8	82.0	8.0		0.21	2.5	0.7	0.0	2.0	63.0	0.0
O. M.	O. C.	S.B.	t	T		B	Cu	Fe	Mn	Zn	
dag kg^{-1}						mg dm^{-3}					
2.8	1.6	3.41	3.41	5.41		0.19	2.6	30.0	10.4	1.4	
Relação entre bases			Relação entre bases e T (%)						Areia	Silte	Argila
$\frac{Ca}{Mg}$	$\frac{Mg}{K}$	$\frac{Ca+MG}{K}$	$\frac{Ca}{T}$	$\frac{Mg}{T}$	$\frac{K}{T}$	$\frac{H+Al}{T}$	$\frac{Ca+Mg}{T}$	$\frac{Ca+Mg+K}{T}$	g kg^{-1}		
3.6	11.9	3.3	15.2	46.0	13.0	37.0	59.0	63.0	633.0	132.0	235.0

P = Mehlich extractor 1, P, K, Na = [HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}], S-SO4 = [Monobaccal Calcium Phosphate 0.01 mol L^{-1}] , Ca, Mg, Al = [KCL 1 mol L^{-1}] / H + Al = [SMP Buffer Solution at pH 7.5], O.M.= Organic matter (Colorimetric Method), O.C.= Organic carbon, S.B = Base Sum, T = CTC pH 7.0; Methodologies of Donagema et al. (2011).

NBPT), in addition to the absolute control (T5- soil without urea) and two controls (T6 and T7 corresponding to products containing 20% NBPT). For the formulation of urea with the Uremax NBPT 500® inhibitor (T2, T3 and T4) 50 grams of untreated commercial granular urea were weighed, followed by the additive at the desired concentrations, at a ratio of 3 kg of additive to one tonne of urea. All weighings were performed to the nearest four decimal places, and at the end the products were homogenized and remained in rest for three days to be poured into the soil. It should be noted that four vessels were reserved to be blank, in which only soil and four vessels were reserved for interpretation of variation of pipetting errors, and these vessels contained 20 g of water. These 8 vessels, white and error control, had the function to enable the identification and elimination of any contaminants.

To assemble the test, the urea granules were placed equidistant from each other on the soil surface with the aid of forceps. Above this a support was used to accommodate a quantitative filter paper/collector. The filter paper disc, here called collector, was held horizontally about 70 mm above the earth, by means of a crown-shaped support. This support was obtained by removing the bottom of a 500 mL disposable plastic jar and trimming the upper border, following a methodology adopted by Duarte (2007).

The evaluations of the ammonia losses were evaluated by the direct method with a static capture system. For this purpose, the volatilization chamber consisted of a cylindrical plastic bottle, 1.8 L capacity, wide mouth, measuring internally 140 mm in diameter and 150 mm in height. The bottle was equipped with a plastic screw cap. Five drops of distilled water were applied to the collector for uniform distribution of the acid solution. After the water droplets, 1 mL of standard sulfuric acid solution was added to the collector at concentrations of 0.1 (on the first day of analysis) and 0.2 mol L^{-1} (other days of the test). An orange gauge drops of methyl (0.1% methyl orange dissolved in 99.9% distilled water) was applied to the collector for the saturation point thereof, at which time the sulfuric acid was totally consumed by the ammonia resulting from the volatilization of urea (Kiehl, 1989).

At the end of each holding period of the collector inside the bottle (24 hours), the collector was replaced with a new one. This removed collector was submerged in 100 mL of distilled water containing four drops of Bromocresol green indicator (1.3% Bromocresol Green dissolved in 25% ethyl alcohol 96% and 74.35% distilled water). The remaining acid was titrated with a standard solution of 0.02 mol L-1 sodium hydroxide (NaOH). The amount of nitrogen volatilized as NH_3 in each period was calculated by the expression: volatilized N-NH_3 = (V 1 - V 2) x 0.28; Where: V1 = volume of NaOH 0.002 mol^{-1} spent on titration of the acid contained in the blank (vessels with only water); V2 = NaOH volume 0.02 mol L^{-1} spent for titration of the remaining acid in the experimental plots. From these data were calculated daily losses and total losses.

The design of the daily volatilization characteristic was completely randomized with four replicates, with plots subdivided in time, forming a factorial at 7 x 11, being plots corresponding to the nitrogen compounds (being conventional urea and those with concentrations of NBPT and three additional: absolute control (soil) and 2 controls (commercial products)) and as subplots the 11 days of evaluation.

The variables were submitted to analysis of variance (Snedecor Test F) to verify the significance of the analyzed factors, respecting the assumptions of normality of residues (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test). The comparison of the means of the absolute controls and of the control was by means of contrasts matched with the other skin treatments of Bonferroni, at 0.01 of significance. Regressions were tested for the time factor and the doses of Uremax NBPT 500®, being chosen significant models, with adjustment higher than 70% based on the dispersion of the data. When the models did not adjust, the comparisons were made by confidence intervals for the mean, using the Student t distribution at 0.05 of significance and when the intervals overlapped, indicated non-significant differences.

Results and Discussion

Ammonia volatilization was time dependent for each nitrogen with or without the NBPT additive, however the ammonia contents released by conventional urea on the first day did not differ from those of the soil in the absence of nitrogen fertilization nor from the commercial urea with NBPT ($0.011 \leq$ Mg $NH^3 \leq 0.294$; Table 2). On the second and third day, the nitrogen volatilization rate in urea without additive was significant (2.765 and 5.411 mg NH_3, respectively), differing from absolute control and control. The volatilization of urea in NH_3 occurs between two and four days after the application (Tasca et al., 2011; Soares et al., 2012; Abalos et al., 2014). It is noteworthy that in these periods urea treated with a 10 to 20% dose of Uremax NBPT 500® did not differ from the ureas with the commercial additives and the absolute control, whose biota was balanced.

From the fourth day, the absolute control results in the lowest levels of volatilized nitrogen for the environment (0.042 mg NH_3). On this occasion and on the fifth day, among the nitrogen treatments, the urea concentrations with Uremax NBPT 500® resulted in the lowest levels of volatilized nitrogen, differing from control 1 (Table 1). On the sixth and seventh days, with volatilized nitrogen contents in the 1.5 mg range, all nitrogen sources resulted in higher levels than the absolute control.

On the sixth day, control 1 regulated nitrogen release more efficiently than urea treated with 15% Uremax NBPT 500®. Subsequent evaluations showed no differences between commercial products, absolute control and urea treated with Uremax NBPT 500®. These results can be explained in part by the dynamics of nitrogen loss over time that is particular to

Table 2. Comparison of ammonia losses (mg NH_3) by volatilization from fertilizer urea (46% N) treated with different concentrations of Uremax Nbpt 500®, commercial products and control.

[1] Nitrogen fertilization	Day										
	1	2	3	4	5	6	7	8	9	10	11
Urea	0.294	2.765 (soil; 1; 2)	5.411 (soil; 1; 2)	3.2060(soil; 1; 2)	3.577 (soil;1; 2)	1.183 (soil)	0.812 (soil)	0.182	0.056	0.133	0.063
Urea (10% NBPT)	0.014	0.049	0.567	1.539 (soil; 2)	1.463 (soil; 2)	1.617 (soil)	1.260 (soil)	0.371	0.119	0.154	0.070
Urea (15% NBPT)	0.000	0.000	0.448	1.329 (soil; 2)	1.022 (soil; 2)	1.526 (soil)	1.694 (soil;1)	0.609	0.196	0.217	0.091
Urea (20% NBPT)	0.018	0.039	0.308	1.532 (soil; 2)	1.505 (soil; 2)	1.491 (soil)	1,365 (sol)	0.294	0.091	0.084	0.084
Soil/Control absolute	0.011	0.123	0.011	0.042 (1;2)	0.042 (1; 2)	0.025 (1; 2)	0,063 (1;2)	0.035	0.012	0.004	0.035
Control 1	0.014	0.119	0.686	1.518 (soil;2)	1.407(soil;2)	1.582 (soil)	0,896 (soil)	0.231	0.133	0.399	0.042
Control 2	0.049	0.084	0.580	1.071 (soil; 1)	2.499 (soil;1)	1.876 (soil)	1,4630(soil)	0.315	0.070	0.098	0.070
K-S = **0,241**; *F'* = **4,096**											

[1] Averages for "soil; 1 and 2 "in the column differ from the control, from control 1 and 2 on each day, respectively, by the Bonferroni test at 0.01 significance; K-S and F': statistics of Kolmogorov Smirnov's test and Levene's test, respectively, values in bold indicate homogeneous variances, residues with normal distribution, respectively, all at 0.01 significance.

each feeder or even dose of Uremax NBPT 500® (Table 2). Therefore, the inhibitor has the efficacy maintained for a week or two, depending on soil temperature, pH, and clay and organic matter content (Bremner & Chai, 1986; Engel et al, 2015).

Soil from crops, as an absolute control, presents a biological equilibrium whose nitrogen and carbon input and output to the system are matched (Horwath, 2015), and therefore resulted in low volatilization over eleven days (Figure 1A), since the decomposed nitrogen was

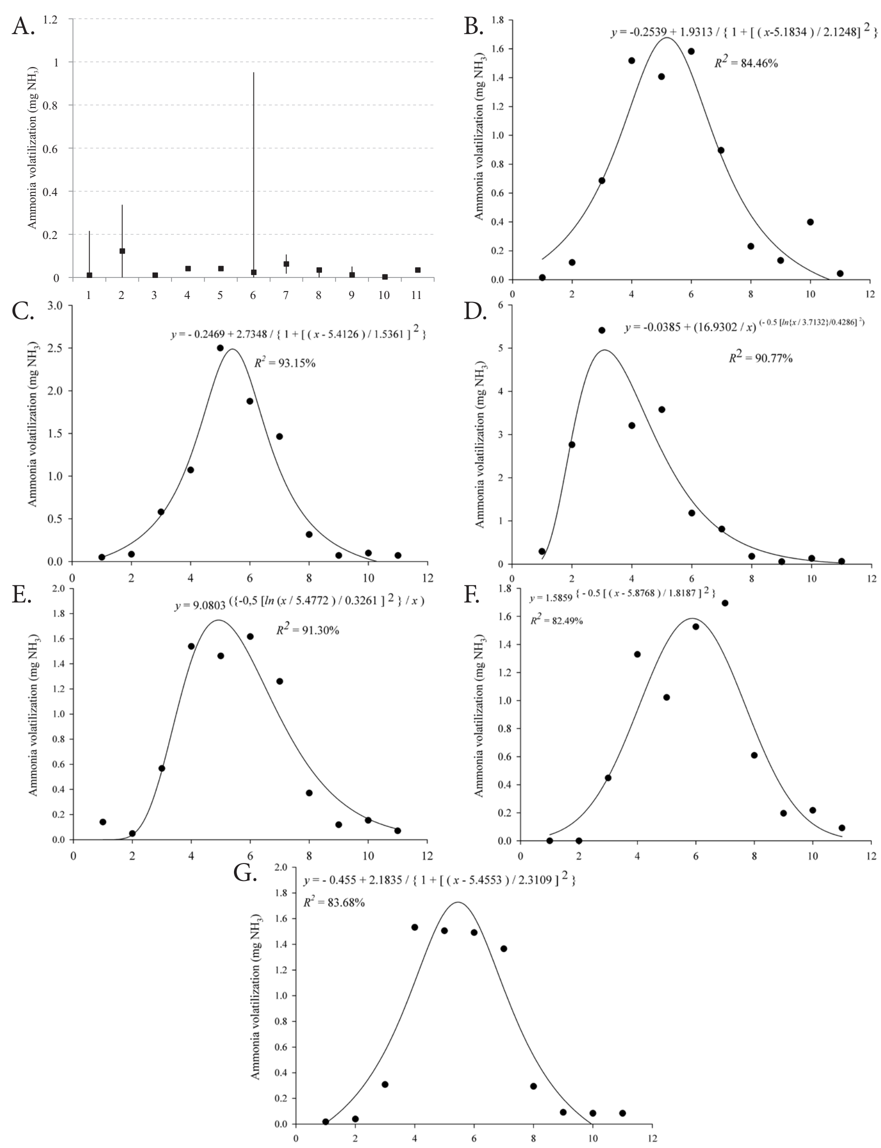

Figure 1. Dynamics of ammonia volatilization (mg NH_3) using the fertilizer urea (46% N) in a period of 11 days. a) control; b) Control 1; c) Control 2; d) urea; and) Urea (10% Uremax NBPT 500®); f) Urea (15% Uremax NBPT 500®); g) Urea (20% Uremax NBPT 500®).

used for the system to keep. For this reason, the averages remained stable, not reaching 0.2 mg of NH_3, and with low variability. In short, the research proved the theory. Due to this behavior the regression models did not adjust, and the comparison was made at 5% confidence intervals. Regarding the behavior of the absolute control over time, a greater variation between the repetitions were observed only in the two initial readings, due to the movement of the same for assembly and conduction of the experiment. After equilibration, which occurred on the third day, the variation between the replicates was even null except on the sixth day (Figure 1A).

Urea, regardless of the use of urea inhibitor, initiates ammonia volatilization at significant values on the second day, but the magnitude is particularly significant for each treatment (Figure 2a, b, c, d, e, f and g). Commercial nitrogen fertilizers enriched with the urea inhibitor and enriched with concentrations of Uremax NBPT 500® ranging from 10 to 20% showed a slow volatilization in the initial stage, not reaching 0.5 mg of NH_3 on the second day (Figure 2c, d, e, f and g). Conventional urea, however, in this same period presented nitrogen emissions four times higher, reaching close to 3 mg of NH_3 (Figure 2b, c, d, e, f and g). Unlike the conventional urea, which on the third day showed a volatilization peak

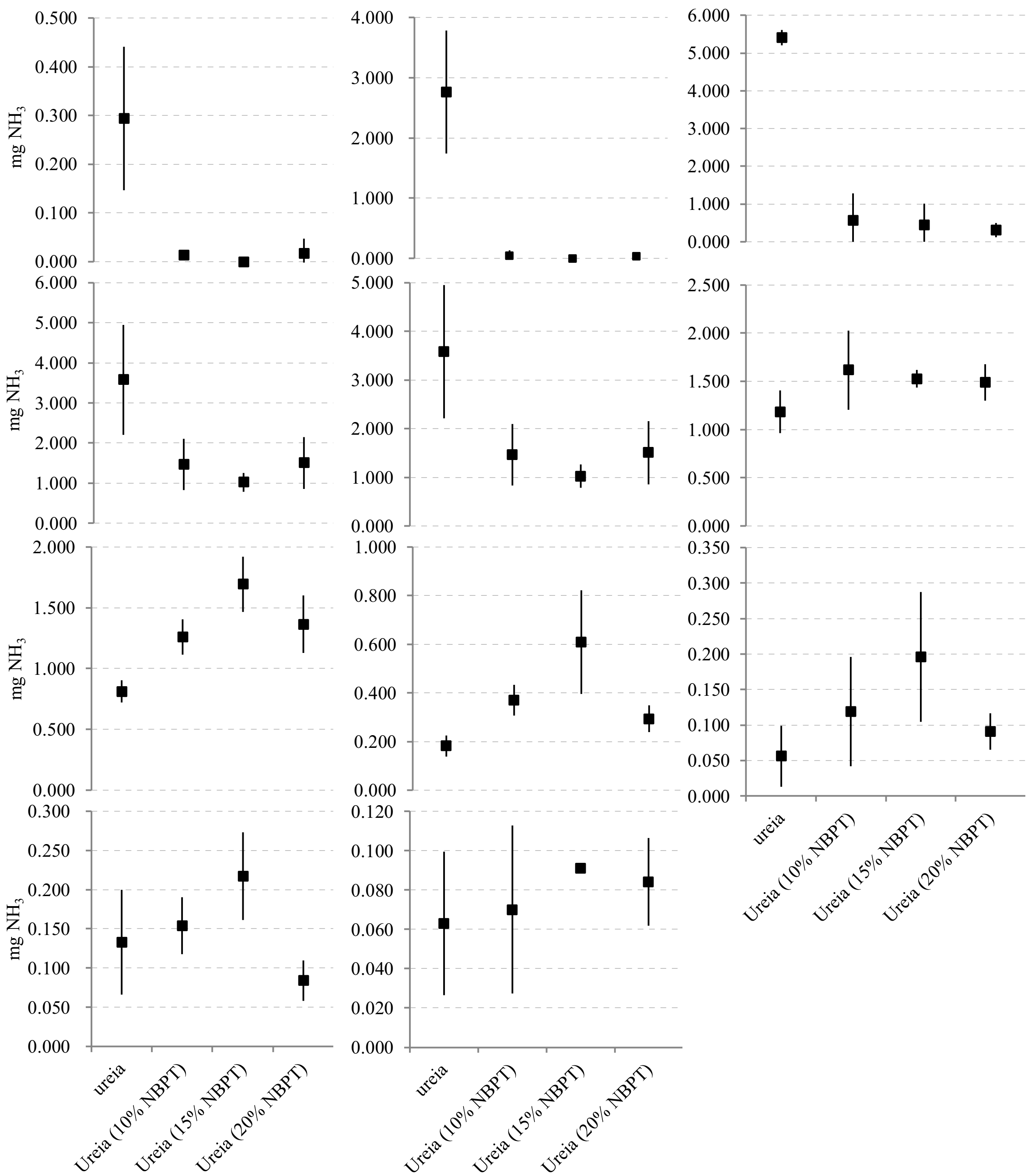

Figure 2. Ammonia volatilization (mg NH_3) with application of fertilizer Urea (46% N) containing NBPT in a period of 11 days: (a) day 1; (b) day 2; (c) 3 day; (d) day 4; e) day 5; f) 6th day; g) 7th day; h) day 8; (i) 9 day; j) 10th day; k) 11 days after the application of urea.

(Figure 2d, approximately 5 mg of NH_3), those with NBPT delayed for the sixth day; And more, the nitrogen losses resulting from those enriched with Uremax NBPT 500® ranging from 10 to 20% were lower (at most 20.5 g NH_3; Figure 2e, f, g) to control 2, which refers to a fertilizer with NBPT, and conventional urea (Figure 2c e, d), approximately 2.5 and 5 mg NH_3, respectively.

The addition of urease inhibitors retards the volatilization peak of $N\text{-}NH_3$ which, for common urea, is concentrated shortly after application of the fertilizer on the soil surface (Cantarella et al, 2008; Tasca et al., 2011). This process is indirect because NBPT is not an active urease inhibitor, but instead has to be converted to the [N- (n-butyl) phosphoric triamide] analogue (NBPTO). Therefore, during the incubation period, the start of the process depends on the relative rate and time of formation of the converted analogues and their soil stability (Okumura et al., 2012). Therefore, the results converge to a higher efficiency of Uremax NBPT 500® in this process, even at lower concentrations than those present in urea traded with NBPT at the standard concentration of 20%.

The products enriched with Uremax NBPT 500® and commercial NBPT ureas (control 1, 2) resulted in symmetry in the release of nitrogen relative to the maximum point (Figure 1c, d, e, f and g). As a possible explanation we have the reduction of the inhibitory effect of NBPT with moisture over time (Tasca et al., 2011), but this does not rule out the possibility of nitrogen source depletion in the soil. Due to the reserve of this nutrient, the data from the conventional urea resulted in a syrup in the curve at the end of the process, showing a still low constancy in the nitrogen release (Figure 1b).

In general, conventional urea resulted in higher volatilization than those with Uremax NBPT 500® in the first five days, showing great dispersion on the first, second, fourth and fifth day (Figure 2a, b, d and f). Even in the first two days it is imperative to mention the low contribution of the variability to discriminate urea with urea inhibitor, i.e., regardless of the dose of Uremax NBPT 500® the volatilization of the ammonia was the same.

On the sixth day, ureas with doses of Uremax NBPT 500® did not differ, and, even with an approximation, the lower variability between the 15% dose repetitions resulted in a difference when compared to conventional urea (Figure 2f). Depletion of the nitrogen reserves of the conventional urea on the seventh day (Figure 1d), resulted in lower nitrogen volatilization of this treatment than those enriched with Uremax NBPT 500® (Figure 2g). Urea with 10% Uremax NBPT 500® more effectively reduced nitrogen losses than 15%. The doses of 15 and 20% of the inhibitor presented on the seventh day the greatest variability, presenting equipolence due to the interception of the mustache wires of the confidence intervals (Figure 2g). Likewise, conventional urea on the eighth day differed from those with Uremax NBPT 500®, with lower volatilized ammonia contents. In addition, the volatilization of urea with 10% Uremax NBPT 500® was equivalent to the highest dose tested (Figure 2h). The reasons for such behavior of urea over Uremax NBPT 500® were distinct, on the seventh day due to the proximity of the averages, associated with moderate dispersions (Figure 2g) and in the eighth due to the great variability seen by the mustache threads and the urea treated with 15% Uremax NBPT 500® (Figure 2h).

Low volatilization of ammonia on the ninth day occurred in conventional urea and in those with 10 and 20% of Uremax NBPT 500®, but the 15% dose did not differ from the others (Figure 2i). On the tenth day the juxtapositions of the mustache wires ensured parity of the means of conventional urea and those treated with 10 and 15% of Uremax NBPT 500®. At this time low ammonia contents were lost by urea with 20% of the additive compared to the other doses tested (Figure 2j). Finally, at the end of the experiment at 11 days, due to nitrogen source depletion, there was no difference between conventional urea and those treated with Uremax NBPT 500®.

The nuances of the treatments within each time reflect peculiarities inherent to the urea used and dose of the urea inhibitor in the dynamics of release of nitrogen volatilization (Figure 2). In addition, Tasca et al (2011) had warned that the addition of the urea inhibitor to urea delayed the maximum loss peak, but did not necessarily reduce the total losses, but did not report the nuances of how this occurs, as seen here. This assertion corroborates the final result of the nitrogen loss, in which the soil without application of nitrogen fertilizer showed loss of 0.39 mg of ammonia, differing from all products with NBPT and conventional urea. Urea with commercial NBPT additive, denominated control 2, presented higher volatilization than those with 15 and 20% doses of Uremax NBPT 500®. Control 1, which is another urea with commercial NBPT additive, lost 6.92 mg of ammonia and was equated with 10, 15 and 20% Uremax NBPT 500® enriched urea (Figure 3).

Two conclusions from the study were established: first, the urease inhibitor decreased nitrogen losses by 50% and

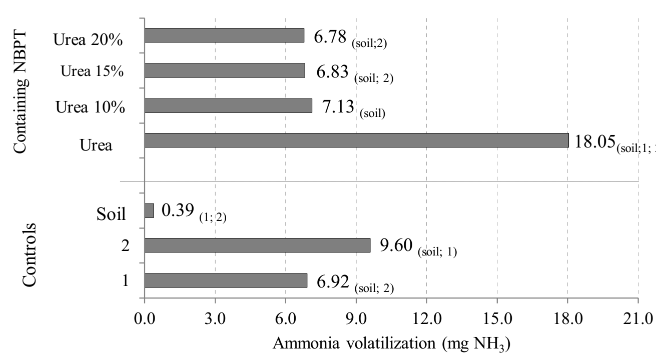

Figure 3. Sum of losses of ammonia (mg NH_3) by volatilization from urea (46% N) containing Uremax Nbpt 500®, commercial products and control after 11 days. Medium followed soil; 1 and 2 differ from the control, the control 1 and 2 respectively, the Bonferroni test the 0.01 significance level. Statistics of the Kolmogorov Smirnov, K-S = 0.211, and Levene's test, F'= 2.196; values in bold indicate variances homogeneous, normal distribution, respectively, both the 0.01 significance level.

75% over conventional urea; and second, regardless of the urea inhibitor, the losses occur at least 17.38 times higher than the stabilized soil, without mineral supplementation (Figure 3). Therefore, the use of NBPT brings several benefits such as those mentioned by Khan et al. (2014) which are (I) late hydrolysis of urea, which reduces nitrogen losses; (II) additional time for the lateral and descending movement of nitrogen in the soil; (III) reduced nitrification; and (IV) there is the possibility of more efficient N uptake and conversion to vegetable protein, through the synchronism in nitrogen availability and crop demand.

Even with particularities over time (Figure 1), the doses of Uremax NBPT 500® applied in conventional urea reduced, from the 10% dose, to the same intensity the ammonia volatilization (Figure 4). This behavior adjusted the decreasing exponential curve (R^2 = 99.90%), so at the beginning there was a severe reduction of NH_3 release, reaching stability around the 10% dose of Uremax NBPT 500®, in which decreases in volatilization of ammonia are practically zero (Figure 4). A similar result to that obtained by de Watson et al. (1994), with 16 soils, with the inhibitor being added to urea in doses of 100 to 2800 mg kg $^{-1}$ (0.01% to 0.28%). At 580mg kg^{-1} (0.058%) the NBPT reduced the volatilization of NH_3 by 68%; Above this dose, there was little difference, reaching the maximum inhibition at the dose of 1000 mg kg^{-1} (0.1%), which corresponded to 80% reduction. Cantarella (2007) showed that NBPT at the dose of 580 mg kg^{-1} (0.058%) reduced volatilization of NH_3 by 68%. In this experiment the dose used corresponded to 600 mg kg-1 (0.06%), 450 mg kg^{-1} (0.045%) and 300 mg kg^{-1} (0.030%) for dilutions of 20, 15 and 10%, respectively. The results of several authors show a reduction of volatilization of ammonia with the use of the NBPT urease inhibitor and that this is efficient at low doses, whose increase does not necessarily result in reduction of volatilization (Watson et al.; 1994; Trenkel, 1997; Rawluk et al., 2001; Cantarella et al., 2008; Scivittaro, 2010). In short, smaller doses of Uremax NBPT 500® are sufficient to reduce ammonia volatilization.

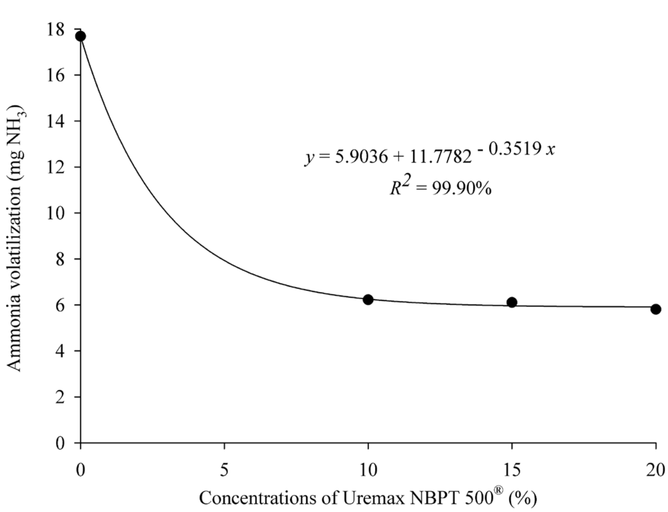

Figure 4. Total of Urea (46% N) treated with concentrations of Uremax NBPT 500®.

Conclusions

The volatilization process of conventional granulated urea ammonia is high, starting on the second day (2,765 mg NH_3) and the use of the inhibitor reduces the volatilization peak in up to four days. Doses of 10% to 20% of the Uremax NBPT 500 inhibitor generally resulted in the same reduction of daily volatilization as commercial products. In the final balance, urea treated with Uremax NBPT 500® reduced nitrogen losses by approximately 75% after 11 days. Even with particularities over time, the doses of Uremax NBPT 500® from 10% applied in conventional urea reduced in equal intensity the volatilization of ammonia, remaining stable in 6 mg NH_3.

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