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Assessment of ammonia volatilization losses from urea application under different soil and climatic conditions

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Abstract

While urea is the world's most widely used nitrogen fertilizer, a surprising share of it never reaches the crop—it escapes as ammonia gas before plant roots can absorb it. This research measured ammonia (NH_3) volatilization losses from surface-applied urea across five contrasting soil types under controlled temperature and moisture conditions at the University of Buenos Aires, Argentina, between March and August 2022. Losses ranged from 8.4 to 36.8 percent of applied N depending on soil type, temperature, and moisture regime. Sandy loam soil at pH 8.2 and 35 °C produced the highest cumulative loss (36.8%). Soil pH was the strongest predictor ($r^2 = 0.87$) of total volatilization. Splitting urea application and shallow incorporation reduced losses by 47 to 62 percent across soil types.

Keywords: Ammonia volatilization, urea, nitrogen loss, soil pH, urease activity, temperature, soil texture, fertilizer management, nitrogen use efficiency, Argentina

Introduction

Urea supplies nearly half the world's fertilizer nitrogen, yet under certain field conditions, more than a third of the applied N can be lost as ammonia gas before reaching the root zone ^[1]. This paradox—that the most popular N source is also one of the most volatile—has been recognized for decades, but site-specific loss estimates remain scarce for many soil-climate combinations ^[2].

Ammonia volatilization from surface-applied urea follows a well-characterized pathway. Soil urease hydrolyzes urea to ammonium and bicarbonate, raising the local pH around each granule. At pH above 7.5, the equilibrium shifts from NH_4^+ toward dissolved NH_3 , which then escapes from the soil surface as gas ^[3, 4]. Temperature accelerates both urease activity and NH_3 diffusion, while soil moisture affects the dissolution rate and surface drying dynamics ^[5].

Argentina's Pampas region includes soils ranging from alkaline sandy loams to slightly acidic silt loams, and seasonal temperatures span 5 to 38 °C, creating wide variation in volatilization risk. This research aimed to quantify NH_3 losses from urea across five representative Pampean soil types under three temperature and two moisture regimes, and to evaluate whether split application and shallow incorporation could reduce losses.

Experimental Design

The experiment used a factorial completely randomized design with five soil types, three temperatures (15, 25, and 35 °C), and two moisture levels (field capacity and air-dried surface), replicated four times (120 experimental units). Soils were collected from five locations across Buenos Aires Province representing distinct textural classes: sandy loam (Junín), clay loam (Pergamino), silt loam (Lobos), silty clay (Chascomús), and sandy clay loam (Mercedes). Urea was applied at 150 kg N/ha equivalent on the soil surface in polyethylene containers (15 cm diameter, 10 cm depth). An additional set of 40 units tested split application (two equal doses at 0 and 7 days) and shallow incorporation (mixed into top 3 cm) on the two highest-loss soils.

Controlled Environmental Conditions

Temperature-controlled incubation chambers (Percival Scientific, Model I-36VL) maintained 15 ± 0.5 °C, 25 ± 0.5 °C, and 35 ± 0.5 °C with 12-hour light/dark cycles.

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Relative humidity was held at 65 ± 3 percent. For the field-capacity treatment, soils were brought to -33 kPa matric potential before urea application; for the air-dried surface treatment, soils were allowed to dry to 40 percent of field capacity at the surface (top 2 cm) while maintaining moisture below. Wind speed across the soil surface was standardized at 0.3 m/s using a small fan. The monitoring period was 14 days per run.

Material and Methods

Material

Soils were collected from the 0–15 cm layer at each site in February 2022, air-dried, and sieved to 2 mm. Soil properties ranged as follows: pH 6.1–8.2, organic carbon 0.87–2.31 percent, CEC 11.4–28.7 cmol/kg, and clay content 14–47 percent. Prilled urea (46% N, Profertil S.A., Argentina) was used. Boric acid (2%) and HCl (0.1 N) for NH_3 trapping were analytical grade from Merck. The research was conducted at the Soil Chemistry Laboratory, University of Buenos Aires, from

March to August 2022.

Methods

Ammonia volatilization was measured using a semi-open static chamber method [6]. Sponge discs soaked in 2 percent boric acid with mixed indicators were placed 5 cm above the soil surface and replaced every 24 hours for 14 days. Trapped NH_3 was back-titrated with 0.1 N HCl to determine daily loss. Cumulative loss was expressed as percentage of applied N. Soil urease activity was measured at 0, 3, 7, and 14 days using the non-buffered method with urea as substrate [7].

For the mitigation treatments, split application delivered 75 kg N/ha at day 0 and 75 kg N/ha at day 7; incorporation mixed urea into the top 3 cm immediately after application. Data were analyzed by three-way ANOVA (soil $\times$ temperature $\times$ moisture) in InfoStat v2020, with means separated by Tukey's HSD at $P \leq 0.05$.

Results

Table 1: Cumulative ammonia volatilization loss (% of applied N) after 14 days at field capacity

Soil type (pH)	15 °C	25 °C	35 °C	Mean	Q_{10}
Sandy loam (8.2)	18.7	27.4	36.8	27.6	1.41
Sandy clay loam (7.9)	13.1	19.6	28.3	20.3	1.47
Clay loam (7.4)	9.8	15.3	22.1	15.7	1.50
Silt loam (6.8)	6.4	11.2	16.7	11.4	1.62
Silty clay (6.1)	3.9	6.8	11.4	7.4	1.71

Q_{10} = temperature coefficient (ratio of loss at $T+10$ to loss at T). Tukey's HSD ($P \leq 0.05$): Soil = 2.3; Temperature = 1.8; Interaction = 3.7.

Ammonia loss increased consistently with both soil pH and temperature (Table 1). Sandy loam at pH 8.2 and 35 °C lost 36.8 percent of applied N, compared to just 3.9 percent from silty clay at pH 6.1 and 15 °C. The temperature effect was more pronounced in acidic soils (Q_{10} of 1.71 for silty clay) than in

alkaline ones (Q_{10} of 1.41 for sandy loam). Air-dried surface conditions increased losses by 18 to 31 percent over field capacity across all soil-temperature combinations (data not shown).

Table 2: Effect of mitigation strategies on NH_3 loss (% of applied N) in two high-loss soils at 25 °C

Treatment	Sandy loam (8.2)	Sandy clay loam (7.9)	Reduction (%)
Surface broadcast (control)	27.4	19.6	-
Split application	14.6	10.4	46.7–47.0
Shallow incorporation	10.3	7.8	60.2–62.4
Split + incorporation	6.8	4.9	75.0–75.2

All treatments significantly different from control at $P \leq 0.01$.

Splitting urea into two doses reduced losses by about 47 percent, while shallow incorporation cut losses by 60–62 percent (Table 2). Combining both strategies reduced NH_3 loss by 75 percent,

bringing even the highest-loss sandy loam soil down to 6.8 percent of applied N.

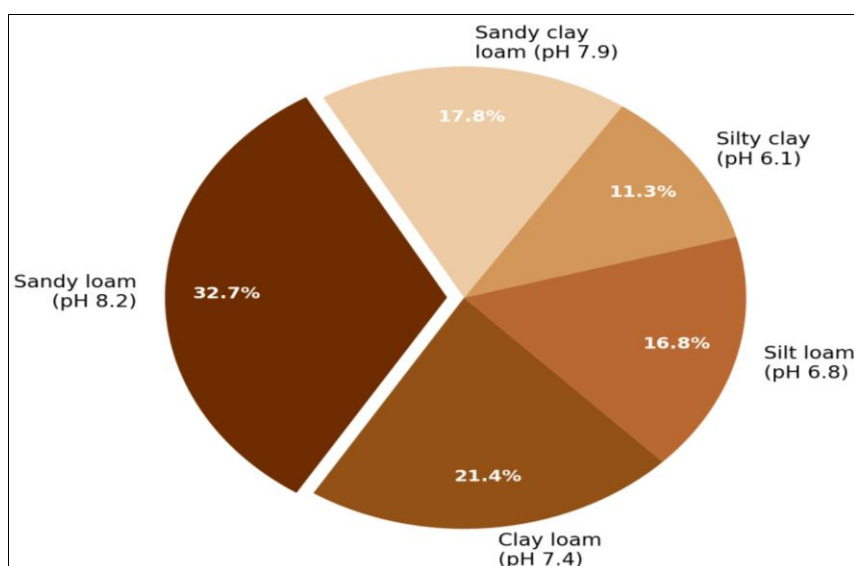


Fig 1: Proportional contribution of each soil type to total ammonia volatilization loss across all temperature-moisture combinations.

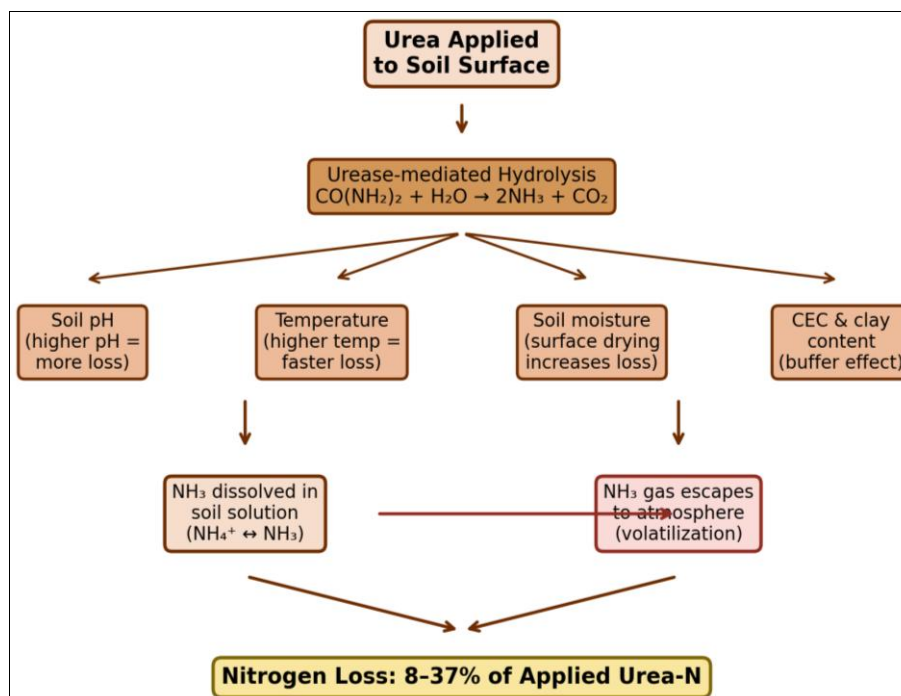


Fig 2: Flowchart of the urea hydrolysis and ammonia volatilization pathway, showing key soil and environmental factors influencing loss magnitude.

Soil pH alone explained 87 percent of the variance in cumulative NH_3 loss ($r^2 = 0.87$, $P < 0.001$). When temperature was added as a second predictor, the model r^2 increased to 0.94. Urease activity peaked within 48 hours of urea application across all treatments and declined to near-background levels by day 7, indicating that most volatilization occurred during the first week.

Limitations

This research was conducted under controlled laboratory conditions, which may not fully capture field-level variability in wind speed, rainfall events, and diurnal temperature fluctuations that affect volatilization dynamics. Soil columns of 10 cm depth may underestimate the buffering capacity of deeper soil profiles. The semi-open chamber method, while widely used, can slightly alter the microenvironment above the soil surface. Extrapolation to field conditions should be made cautiously, and field validation trials across the Pampas would strengthen the applicability of these results.

Discussion

The strong pH dependence of NH_3 loss confirms decades of laboratory and field research [8, 9]. At pH above 7.5, the $\text{NH}_4^+/\text{NH}_3$ equilibrium shifts sharply toward the volatile form, which explains why the sandy loam (pH 8.2) lost nearly five times as much N as the silty clay (pH 6.1) at identical temperatures. The Q_{10} values of 1.41–1.71 are consistent with the temperature sensitivity range reported by Sommer *et al.* [10] for European soils.

The 75 percent loss reduction from combining split application with shallow incorporation has practical significance for Argentine wheat and maize production, where surface broadcasting of urea remains the dominant practice [11, 12]. Even simple incorporation to 3 cm depth was sufficient to place dissolved urea below the zone of rapid gas exchange, reducing surface NH_3 concentration by over 60 percent. These findings support recommendations by Rochette *et al.* [13] that mechanical

incorporation should be the default practice on alkaline soils.

Conclusion

Ammonia volatilization from surface-applied urea ranged from 3.9 to 36.8 percent of applied N, with soil pH as the dominant controlling factor. Alkaline sandy soils at high temperatures are the highest-risk scenario. Splitting urea application and incorporating it to 3 cm depth together reduced losses by 75 percent.

For Argentine Pampas farmers, shallow incorporation of urea on soils with pH above 7.5 should be standard practice, particularly during warm months. Where incorporation isn't feasible, split application alone can cut losses nearly in half.

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