Urea Volatilization Losses from Coffee Plantations

By Luis Leal, Alveiro Salamanca, and Siavosh Sadeghian

Responses to N are common in the coffee growing areas of the world. In Colombia, N recommendations vary from 120 to 300 kg N/ha/year, according to soil organic matter content, shade level, and plant density. Yield reductions of 30 to 50% are expected when N is not applied to the crop. Urea is the most common source of N used in coffee production in Colombia due to its high N content and relatively low price per unit. High N losses via volatilization from broadcast-applied urea are expected under the climate and soil conditions prevalent in the coffee production areas in Colombia. However, field research in the country to quantify the magnitude of these losses has been lacking.

A field study was conducted during 2005 to 2007 at two sites located at CENICAFE (Colombian Coffee Research Center) Experiment Stations. The sites are Naranjal and Paraguaicito, situated in the Departments (States) of Caldas and Quindío, respectively, in the heart of the Colombian coffee growing region. Climatic conditions of both sites are presented in **Table 1**. Soils are classified as Melanudands and Hapludands at Naranjal and Paraguaicito, respectively. Physical and chemical characteristics of both soils are presented in **Table 2**.

A coffee field in the peak of the production cycle (3 years of age) was chosen at each experiment station as a study site. Each field was planted with the Colombia coffee variety at 6,700 plants/ha managed at complete sunlight exposure. Ten blocks of two coffee plants were located inside each field. Each tree was an experimental unit. A PVC cylinder was placed 30 cm from the trunk to quantify NH_3 volatilization (observation unit). One experimental unit was fertilized superficially with 6.5 g of urea, while another corresponding unit did not receive urea and was considered the control or check treatment.

Each observation unit consisted of a static half-open collector made from a PVC cylinder that was 15 cm in diameter and 44 cm in height. Inside this cylinder, two laminar pieces of polyurethane (3 cm thick) were placed 15.4 cm apart from each other **(Figure 1)**. Each piece was soaked in 70 ml of a 0.5N sulfuric acid solution + 3% glycerin. The lower foam trapped the NH_3 liberated from the soil, while the upper lamina prevented the penetration of NH_3 from the atmosphere (Nömmik, 1973; Lara et al., 1999).

Ammonia volatilization was measured at days 1, 2, 3, 5, 9, 14, and 20 after urea application. The polyurethane laminas in every cylinder were replaced each day of evaluation and water was added in the same volume as the rain collected in adjacent containers. The bottom lamina was taken to the lab to determine the amount of NH_3 volatilized. Daily data of mean air temperature and rainfall was collected during the period of evaluation at two weather stations located near the evaluation sites.

Abbreviations and notes: N = nitrogen; NH_3 = ammonia; NH_4^+ = ammonium; CEC = cation exchange capacity.

Table 1. Climatic conditions prevalent at the two experimental sites (CENICAFE, 2005).

Site	Altitude, m	Temperature, °C	Relative humidity, %	Solar radiation, hr/year	Precipitation, mm/year
Naranjal	1,381	21.3	73.1	1,797	2,711
Paraguaicito	1,203	21.9	77.0	1,720	2,149

Table 2. Physical and chemical characteristics of the soils at the two experimental sites.

Site	Sand	Silt	Clay	Organic matter	pH	CEC
	----------------		%	----------------		cmol+/kg
Naranjal	49	32	19	11.3	4.8	23
Paraguaicito	54	27	19	7.1	5.2	13

Table 3. Average values of N volatilization losses from coffee plantations at two evaluation sites in Colombia.

		------------ Days after application ------------						
Site	Treatment	1	2	3	5	9	14	20
		-------------------- mg --------------------						
Naranjal	- urea	0.60	0.61	0.59	0.55	0.57	0.42	0.40
	+ urea	22.0	257.7	199.9	205.1	119.6	64.0	43.9
Paraguaicito	- urea	0.89	0.87	0.86	0.87	0.88	0.95	0.86
	+ urea	13.4	279.6	260.7	263.3	126.5	68.1	33.9

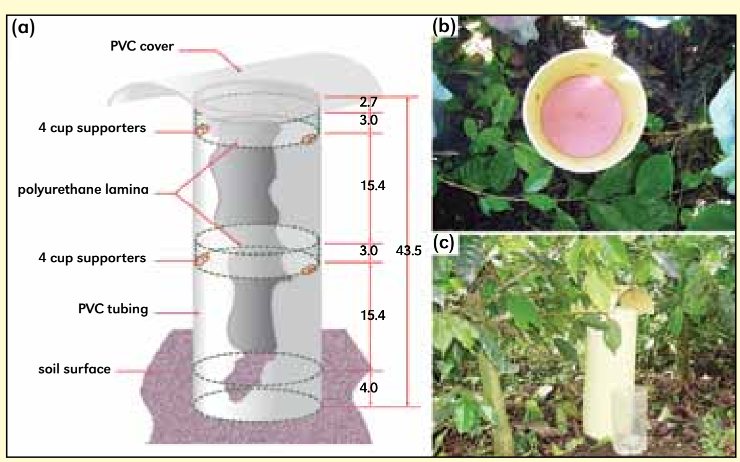

Figure 1. a) Diagram of the NH_3 collector. b) NH_3 collector with the lower polyurethane lamina installed. c) NH_3 collector in the field.

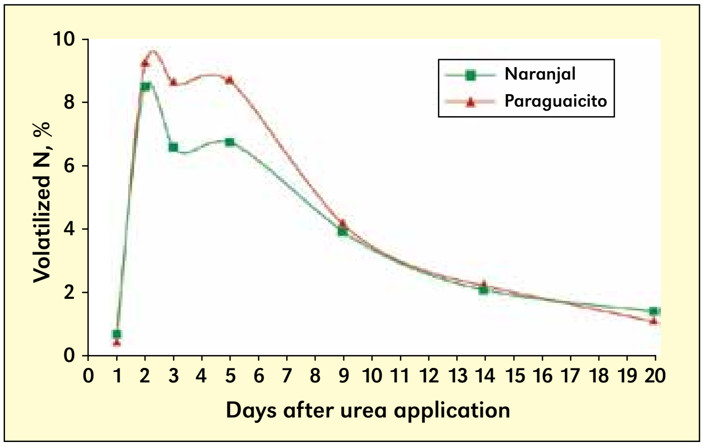

Figure 2. Average daily N losses at both evaluation sites.

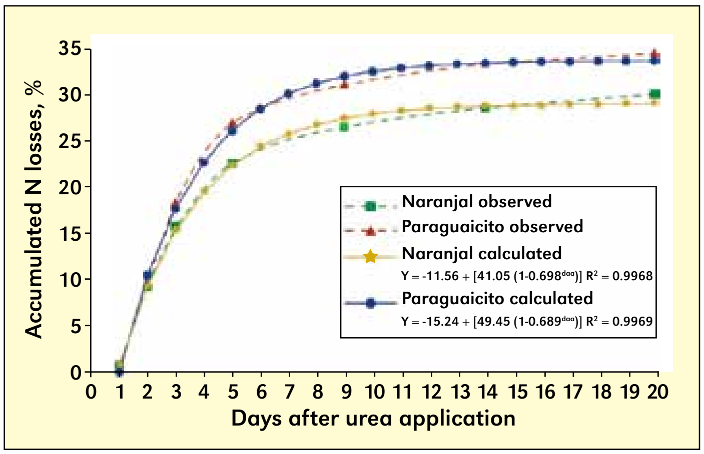

Figure 3. Accumulated observed and calculated N losses at both evaluation sites.

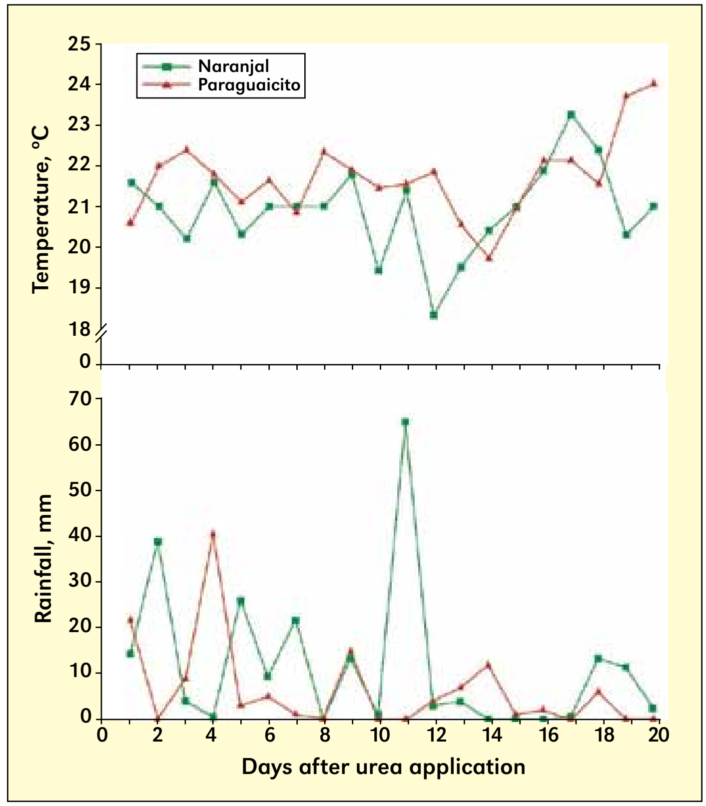

Figure 4. Mean daily air temperature and mean daily rainfall registered at the weather stations in Naranjal (March 14 to April 2, 2006) and Paraguaicito (April 27 to May 16, 2006) Experiment Stations.

Results and Discussion

The mean volatilization losses through time at both locations are presented in **Table 3**. At both sites, N losses from the surface applied urea treatment were significantly higher than the control without N application. The background N losses were very low and relatively constant through time. Background losses at Paraguaicito were higher (0.87 to 0.95 mg of N) than at Naranjal (0.40 to 0.61 mg of N). These background losses are in agreement with data reported in the literature for similar treatments (Barbieri and Echeverría, 2003; Sangoi et al., 2003) and probably are N forms liberated by regular microbial and plant activity.

The trend of N volatilization from the urea treatments was similar at both locations, with low losses the first day after application and a significant increase on the second day, moving from 22.0 to 257.7 mg of N at Naranjal and from 13.4 to 279.6 mg at Paraguaicito. Losses from the third to fifth day at Naranjal were slightly lower to those recorded on the second day, but were similar to those recorded on the second day at Paraguaicito. The amount of N volatilized decreased gradually at both sites from the fifth day until day 20 when the lowest N loss was registered.

The high N losses during the first days after urea application are a consequence of urea hydrolysis, which increases ambient pH around the granule, a condition that promotes NH_3 formation from the NH_4^+ formed during the initial reaction between urea and the soil surface (Kiehl, 1989; Vitti et al., 2002).

The daily losses, expressed as a percentage of the total N application, showed a similar volatilization trend at both sites **(Figure 2)**. Accumulated N losses are presented in **Figure 3**. Total N volatilization at the end of the evaluation period at Naranjal was 30% of the total N application, while 35% was volatilized at Paraguaicito. Ammonia volatilization during the first 5 days of evaluation was very high and reached 23% of the total N application at Naranjal and 27% at Paraguaicito. These N losses are similar to those reported for sugarcane plantations in Brazil (Costa et al., 2003).

Figure 3 also shows the accumulated data calculated with the best fitted regression model using the observed data at both sites. Observed and calculated data indicate that NH_3 losses reached a minimum at day 20. If the assumption is made that accumulated volatilization at day 20 represents 100% of the N losses, recorded data suggest that more than 95% is volatilized 10 days after urea application. This indicates that volatilization occurs in a short period of time and practices to minimize these losses need to be adjusted to this condition.

The difference in total loss between both sites could be associated with the soil and climatic characteristics of the experimental sites. Soil characteristics such as organic matter content, CEC, texture, and pH affect the magnitude of volatilization. Soils with higher CEC and higher organic matter content have a greater capacity to retain NH_4^+ released from the urea hydrolysis and this reduces volatilization (Fenn and Kissel, 1976; Fleisher et al., 1987). Data from this study suggest that differences in soil characteristics could be responsible for the differences in total volatilization losses since organic matter content and CEC were higher at Naranjal in comparison with the soil at Paraguaicito. However, the differences in soil pH and texture between the soils of both sites were likely not significant enough to explain the differences in the observed NH_3 volatilization.

It has been documented in coffee plantations in Colombia that air temperature in the top 2 m over the ground is highly correlated with temperature in the first 10 cm of the soil profile (Jaramillo, 2005). This condition is in turn influenced by other climate factors such as solar radiation, wind velocity, water evaporation, rainfall, and soil factors including tillage, organic matter content, and soil moisture. **Figure 4** shows the average temperature registered over the 20 days of evaluation at both sites. The data suggest that the lower average temperature at Naranjal during the evaluation period was associated with lower N volatilization losses. Volatilization losses are greater as temperature increases due to the increment in microbial activity, particularly microorganisms that produce the urease enzyme (Hargrove, 1988).

Figure 4 also shows daily precipitation through the evaluation period at both sites. At Naranjal, total accumulated precipitation during the 20 days of evaluation was 252 mm, while at Paraguaicito it was only 128 mm. The lower N volatilization at Naranjal can be related to the higher amount of rainfall during the first five days of evaluation, or the period when the highest amount of N losses occurred at both sites. Higher soil moisture due to more rainfall reduces N volatilization losses because it dilutes the concentration of OH^- ions that builds around the urea granule during urea hydrolysis and helps to incorporate NH_4^+ into the soil profile (Lara et al., 1997).

The combined plant density and age condition of the plantation could explain the fact that 40 mm of precipitation on day 2 at Naranjal did not move the urea far enough into the soil to shut down volatilization losses. Around 50% of the total amount of water which falls in a precipitation event is retained in the coffee plant canopy and in the thick mulch layer accumulated on the soil as a result of normal leaf loss and trimming (Jaramillo, 2003; Velásquez y Jaramillo, 2009). Consequently, only around 50% of the rainwater reached the soil to upset urea reactions at that point in time.

Conclusions

Data from this study demonstrate that NH_3 volatilization losses from urea applied to the soil surface in established coffee plantations are significant and occur over a short period of time. The combined effect of soil and climate influence the total N loss, but in any situation it is necessary to adjust fertilizer management practices to minimize these losses. BC

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