Laboratory measurements and simulations of ammonia volatilization from urea applied to calcareous Chinese loess soils

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Abstract

Ammonia volatilization is the major pathway for mineral nitrogen loss in the calcareous soils of the Chinese loess plateau, with maximum losses reaching 50% of the fertilizer-N applied. A volatilization-diffusion experiment was carried out in the laboratory using a forced-draft system and soil columns of 15.5 cm depth. Urea was surface applied at rates of 210 kg N ha⁻¹ to a soil with 10% CaCO₃ and a pH of 7.7. The amount of ammonia volatilized as well as the concentration profiles of ammoniacal-nitrogen and soil pH in the upper 50 mm of the soil columns after 4, 7 and 10 days were measured and subsequently modelled. The mechanistic model of Rachhpal-Singh and Nye, originally developed for neutral, non-calcareous soils, was modified to include the pH-buffering action of the soil carbonates. Model parameters were independently determined or taken from the literature. Measured and predicted cumulative NH₃ losses agreed very well in the first 10 days following fertilizer application. However, in contrast to the simulations, NH₃-volatilization was still proceeding in the experiment even after 13 days, with cumulative losses reaching 60% of the applied N. In addition to the high initial soil pH, the low bulk density and high volumetric air content of the soil columns used for the experiment proved decisive for the high rates of ammonia volatilization, provoking a strong increase in the amount of ammoniacal-N diffusing towards the soil surface as gaseous NH₃. The simulations showed that due to the high soil pH, the buffering action of the soil carbonates played a comparatively smaller role.

Introduction

The region at the southern edge of the loess plateau in Shaanxi Province, China, has a subhumid climate and topsoils with a pH of 7.7 and high carbonate content. A double crop winter wheat (Triticum aestivum L.) - summer maize (Zea mays L.) rotation is practiced. Ammonium bicarbonate (NH₄HCO₃) and urea are the predominant mineral nitrogen fertilizers, applied at average rates of about 150 (maximum 200) kg N ha⁻¹ per crop, usually in a single application. The forms of N-fertilizer and these high application rates lead to ammonia volatilization as main pathway of nitrogen loss. As much as 32% of urea-N applied can be lost by volatilization from calcareous soils in northern China (Zhang et al., 1992), and losses from NH₄HCO₃ applied to summer crops usually exceed those from urea. Extensive in situ and laboratory measurements of NH₃-volatilization using a forced-draft system have been carried out in earlier experiments (Roelcke, 1994). In the laboratory, total NH₃ losses after 17–21 days amounted to 66% and 51% of the surface applied N for NH₄HCO₃ and urea respectively. In field trials using ¹⁵N-labelled urea, the amounts of unaccounted for fertilizer-N ranged from 43% to 62% for summer maize and from 36% to 46% for winter wheat (Rees et al., 1996).

NH₃-volatilization rates are controlled by many different processes, with significant interactions occurring between variables (Kirk and Nye, 1991). The relationships between NH₃-volatilization, soil pH and the buffering action of CaCO₃ have been described both theoretically and experimentally (Avnimelech and Laher, 1977; Ferguson et al., 1984; Vlek and Stumpe,
Figure 1. Measured and modelled soil pH profiles in the soil columns at three different diffusion times after surface application of urea (simulations A-D).

For a neutral, carbonate-free soil, the diffusion of HCO$_3^-$-ions to the soil surface, resisting the decrease in surface pH caused by the reaction NH$_4^+$ $\leftrightarrow$ NH$_3$ + H$^+$, was shown to be the main rate limiting process of NH$_3$-volatilization in Rachhpal-Singh and Nye's (1986) measurements and simulations. So far, existing simulation models of NH$_3$-volatilization do not properly account for the effect of high soil CaCO$_3$-contents on changes in soil pH resulting from urea hydrolysis and ammonia volatilization. The purpose of this study was to examine the influence of a high CaCO$_3$-content and soil pH as well as relatively dry soil conditions on ammonia volatilization following urea application.

Materials and methods

Experiment

A laboratory volatilization-diffusion experiment with forced-draft system, similar to the one described by