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Urea super granules in a Cambisol: N transformations, nitrous oxide and ammonia emissions at two soil water regimes

M. I. Khalil[1, 2], U. Schmidhalter[2] and R. Gutser[2]

[1] *Soil Science Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh 2200, Bangladesh*
E-mail: khalilmi@bttb.net.bd

[2] *Institute of Plant Nutrition, Department of Plant Sciences, Technical University of Munich, 85350 Freising, Germany*

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Abstract

A comparative study of point-placed urea super granule (USG) with prilled urea (PU) mixed into a silt loam soil was carried out under controlled environmental conditions. Gradients of NH_4^+ and NO_2^- concentrations and of pH around a USG placement zone were influenced by soil water content, i.e., low evaporative (LEC) versus high evaporative conditions (HEC), and irrigation. At HEC, concentrations of NO_2^- increased faster than at LEC, from either urea size, but N_2O emissions were smaller. High N_2O emissions at LEC were probably due to denitrification in anaerobic microsites. At the HEC, nitrification was rapid and short peaks appeared after irrigation, contributing less to the N_2O emissions. Emissions of N_2O were higher from USG-treated soil than from PU-treated soil. Peek emissions from USG treated soils delayed (3-6 days) relative to those from PU-treated soils. Based on the area receiving equal N rate, the USG released 7.5%-21.5% more N_2O than the PU. Overall, the relative loss of added N from all treatments as N_2O ($\leqslant$ 0.20%) and NH_3 ($\leqslant$ 0.56%) in 21 days was small. The N_2O fluxes were best predicted coupled with CO_2, NO_3^- and water-filled pore space (WFPS, $R^2 = 0.67^{***}$), indicating the influence of soil water content on microbial processes and transport processes.

Introduction

Globally urea covers around 50% of the commercial inorganic N fertilizers used for agricultural production. The hydrolysis of urea and the subsequent transformation of ammonia and nitrate with concomitant gaseous N losses depend on urea fertilizer type and soil environment (Khalil *et al.*, 2002a,b). It has been suggested that use of urea super granule (USG) may improve N use efficiency in rice production. Dissolution of deep-placed USG occurs rather slow and inhibits both urease and nitrifier activities (Shah and Wolfe, 2003). However, the consequences of USG for gaseous N loss are not well documented. Tenuta and Beauchamp (2000) showed an increased N_2O production with USG application. Wetting and drying processes are thought to influence N_2O production and diffusion from soils (Delgado and Mosier, 1996). Thus, experiments were conducted to compare the loss of N_2O and NH_3 from point-placed USG with PU under two soil water conditions and to evaluate the movement of mineral N with distance and time.

Materials and methods

This study was carried out using a silt loam soil (Cambisol) filled in polyvinyl boxes mixed with the PU and point-placed USG at 7.5 cm depth under controlled environmental conditions. The soil had a pH ($CaCl_2$) of 6.4, a CEC of 17.6 $cmol_c$ (+) kg^{-1} soil, and a C/N ratio of 9.5 (0.17% N and 1.61% C). Water-filled pore space (WFPS) at field capacity (FC) was 70%. Two soil water levels were induced: low evaporative conditions (LEC; relatively constant but marginally above FC) and high evaporative conditions (HEC; rapid depletion of water from near FC along with two irrigations). Urea rate was 42.5-45.7 kg N ha^{-1} and 15 USGs (wt. ~0.427-0.459 g per USG; dia. ~8.6-8.8 mm) were accommodated in a box at a distance of 0.22 m. To measure N_2O, gas was sampled using a closed chamber (base dia. 0.109 m). The chamber was placed on the top of a USG (USG_{in}), unfertilized space (USG_{out}) and PU (0.086-0.093 g). Ammonia loss was measured up to 21 days following the acid trap method. Soils were sampled at 1.5 ($USG_{1.5}$), 5.0 ($USG_{5.0}$) and 8.5 cm ($USG_{8.5}$) away from the USG placement zone. Based on the area containing the equal N rate as for PU, a value for 1 USG_{in} with 4 USG_{out} were averaged (USG_{av}).

Results and discussion

Gradients of NH_4^+ and NO_2^- concentrations and of pH next to the zone of USG placement developed faster at the HEC than at the LEC. Irrigation events tended to decrease the concentrations of NH_4^+ and NO_2^- (Fig. 1).

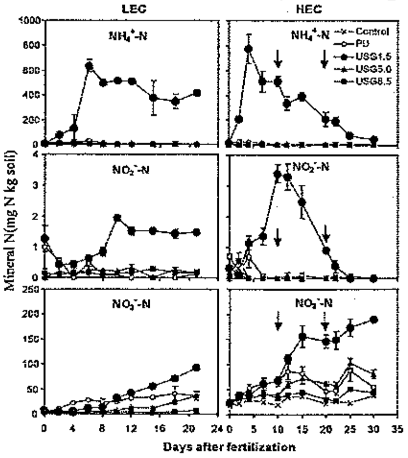

Figure 1. Changes in mineral N content during 21 to 30 days. Arrows and vertical bars indicate the days of irrigation to near FC and standard errors, respectively.

Nitrification was low in the LEC treatment where

WFPS went down from 77 to 69% in 21 days. In the HEC treatment, WFPS decreased from 69% to 50%-56% by 10 days and resulted in rapid nitrification.

LEC gave higher N_2O emissions than HEC (Fig. 2). Likely, N_2O originated from both nitrification and denitrification. In the HEC treatment, short peaks appeared after irrigation, which are probably related to the denitrification events. The initial insignificant response of the urea size to N_2O fluxes may be attributed to the soil N as a major source, low dose of the PU, and dissolution and diffusional constraints of USG. Trends for CO_2 evolution were similar to N_2O fluxes and declined slowly. Irrigation events increased CO_2 fluxes at the HEC but lower than at the LEC, showing an influence of soil water content.

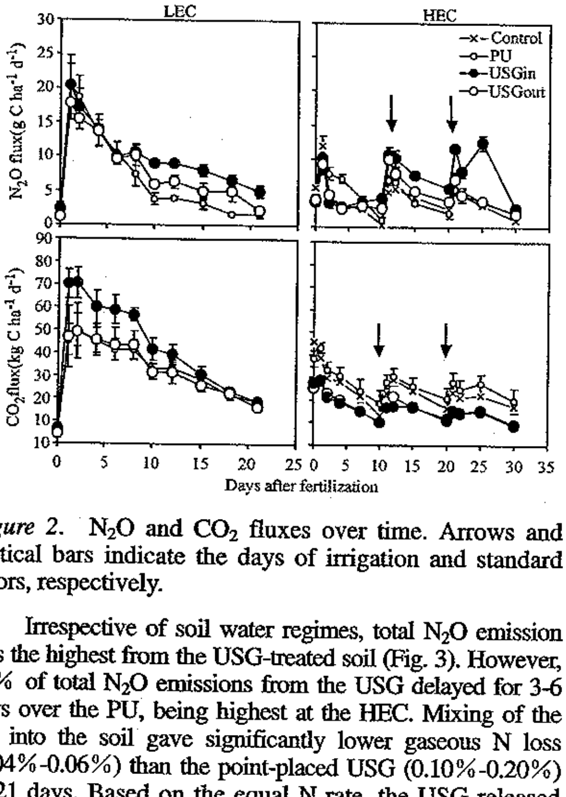

Figure 2. N_2O and CO_2 fluxes over time. Arrows and vertical bars indicate the days of irrigation and standard errors, respectively.

Irrespective of soil water regimes, total N_2O emission was the highest from the USG-treated soil (Fig. 3). However, 50% of total N_2O emissions from the USG delayed for 3-6 days over the PU, being highest at the HEC. Mixing of the PU into the soil gave significantly lower gaseous N loss (0.04%-0.06%) than the point-placed USG (0.10%-0.20%) in 21 days. Based on the equal N rate, the USG released 7.5%-21.5% more N_2O than the PU.

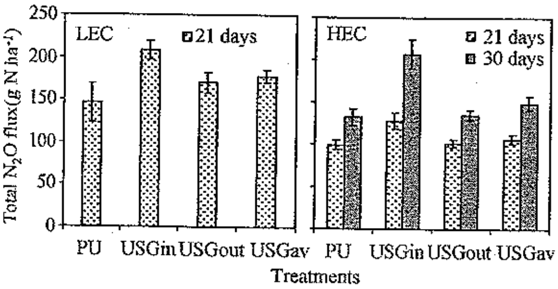

Figure 3. Total N_2O fluxes with two soil water regimes and urea size. Vertical bars indicate standard errors.

NH_3 volatilization during 21 days of collection was very low and represented an insignificant N loss from added PU (0.08-0.24), USGin (0.37-0.56) and USGav (0.16-0.26%), being the highest at the LEC (Fig. 4). Low N losses were ascribed to the incorporation of the PU and point-placement of USG at 7.5 cm soil depth, moderate CEC of the soil, and the addition of water shortly after fertilization. Some movement of urea/ammoniacal-N to the soil surface occurred during the drying process.

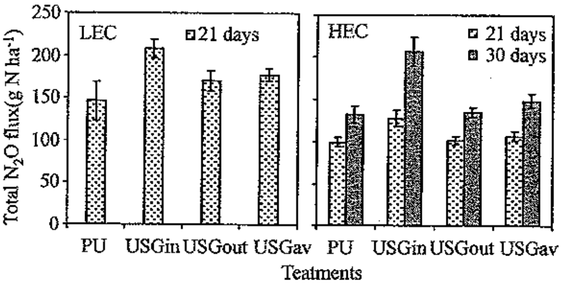

Figure 4. Total NH_3 volatilized during 21 days. Vertical bars indicate standard errors.

The N_2O fluxes were related to CO_2 evolution, NO_3^- and WFPS. This indicates that soil water was an important regulatory factor, and both auto- and heterotrophic microbes probably simultaneously influenced the N_2O emissions. The point placement of USG could delay nitrification, depending on the degree of soil water content, and subsequent release of N_2O. An empirical model is developed using both experimental data, as follows:

$$N_2O\ (g\ N\ ha^{-1}\ day^{-1}) = -10.47 \pm 2.89 + CO_2,\ kg\ C\ ha^{-1}\ day^{-1}\ (0.22 \pm 0.02)^{***} + NO_3^{-}\text{-}N,\ mg\ N\ kg^{-1}\ soil\ (0.04 \pm 0.01)^{***} + WFPS,\ \%\ (0.14 \pm 0.05)^{***}$$

$$(n = 74;\ R^2 = 0.67^{***})$$

Conclusions

High concentrations of NH_4^+ and NO_2^- at the USG placement zone limited the nitrification but presumably accelerated denitrified-N_2O emissions at the LEC. Irrigation to below field capacity or small rainfall events particularly after fertilization can be effective to reduce N_2O and NH_3 emissions from up/dryland soils by mixing the PU into soil or USG deep-placement. N_2O emissions were strongly influenced by soil water content. USG gave higher N_2O and NH_3 losses than PU. We hypothesize that the USG-induced delay in nitrification may improve the recovery of fertilizer N by dry/upland crops.

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