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RESEARCH ARTICLE

Nitrogen mobility, ammonia volatilization, and estimated leaching loss from long-term manure incorporation in red soil

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Abstract

Nitrogen (N) loss from fertilization in agricultural fields has an unavoidable negative impact on the environment and a better understanding of the major pathways can assist in developing the best management practices. The aim of this study was to evaluate the fate of N fertilizers applied to acidic red soil (Ferralic Cambisol) after 19 years of mineral (synthetic) and manure fertilizer treatments under a cropping system with wheat-maize rotations. Five field treatments were examined: control (CK), chemical nitrogen and potash fertilizer (NK), chemical nitrogen and phosphorus fertilizer (NP), chemical nitrogen, phosphorus and potash fertilizer (NPK) and the NPK with manure (NPKM, 70% N from manure). Based on the soil total N storage change in 0–100 cm depth, ammonia (NH_3) volatilization, nitrous oxide (N_2O) emission, N plant uptake, and the potential N leaching loss were estimated using a mass balance approach. In contrast to the NPKM, all mineral fertilizer treatments (NK, NP and NPK) showed increased nitrate (NO_3^-) concentration with increasing soil depth, indicating higher leaching potential. However, total NH_3 volatilization loss was much higher in the NPKM (19.7%) than other mineral fertilizer treatments (≤4.2%). The N_2O emissions were generally low (0.2–0.9%, the highest from the NPKM). Total gaseous loss accounted for 1.7, 3.3, 5.1, and 21.9% for NK, NP, NPK, and NPKM treatments, respectively. Estimated N leaching loss from the NPKM was only about 5% of the losses from mineral fertilizer treatments. All data demonstrated that manure incorporation improved soil productivity, increased yield, and reduced potential leaching, but with significantly higher NH_3 volatilization, which could be reduced by improving the application method. This study confirms that manure incorporation

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is an essential strategy in N fertilization management in upland red soil cropping system.

Keywords: soil NO_3^--N, ammonia volatilization, nitrogen leaching, long-term field experiment, mass balance, nitrous oxide emission

1. Introduction

Overuse of synthetic nitrogen (N) fertilizers due to intensification of agricultural productions has led to high losses from agricultural soils and caused damage to the environment (Erisman *et al.* 2007). China has become the largest N fertilizer consumer accounting for about 30% of the world's consumption since 2002 (FAO 2010). However, for a popular cropping system with winter wheat-summer maize rotation, the N use efficiency (NUE) is less than 30% (Zhao *et al.* 2006). Nitrogen loss has led to surface water eutrophication, ground water contamination, air quality degradation, and contributed to global warming by forming greenhouse gases.

Nitrate leaching losses from soil into water not only reduces soil fertility but also causes threat to environment and human health (Cameron *et al.* 2013). Groundwater contamination has been reported as a major concern in northern China. A survey of NO_3^- concentration in 600 groundwater samples showed that about 45% of the samples exceeded the drinking water standard of 50.0 mg L^{-1} proposed by major developed countries with the highest reported concentration reaching 113 mg L^{-1} (Zhang *et al.* 2004).

Increased concentration and mobility of NO_3^- in soil profile indicates high risk of leaching and groundwater contaimination. In wheat-maize fields, NO_3^--N in the 0–90 cm soil layer was found to accumulate above 200 kg N ha^{-1} at N application rate of 553 kg N ha^{-1} yr^{-1} (Ju *et al.* 2006). The N leaching loss in subtropical areas such as the red soil region in southern China was expected to be worse than northern China because of higher precipitation. However, we have insufficient data to validate (Xu *et al.* 2010). Sun *et al.* (2008) found about 16.8% of N fertilizer applied at 150 kg N ha^{-1} yr^{-1} was leached in a rain-fed peanut rape rotation system in an acidic red soil. Long *et al.* (2012) found that pig manure applied at 150 kg N ha^{-1} yr^{-1} did not result in elevated NO_3^- concentrations in soil, and addition of lime with high manure incorporation rate (600 kg N ha^{-1} yr^{-1}) in surface soil layer (0–15 cm) had no significant effect to reduce NO_3^- concentrations in soil below (15–150 cm). This potentially indicates that N leaching can be significant, if manure application rate is too high.

Ammonia (NH_3) volatilization is one of the major N losses from soil fertilization. High NH_3 loss is caused by a chemical reaction shifting from ammonium (NH_4^+) to NH_3 at high pH ($NH_4^+ + OH^- \rightarrow NH_3\uparrow + H_2O$). The worldwide NH_3 losses range from 10 to 19% (average 14%) of the used N fertilizers (Ferm 1998). In China, high NH_3 volatilization has been reported from calcareous soil (high soil pH) in the Northern China Plain. The NH_3 losses were 30–39, 11–48, and 1–20% of total N applied to rice (urea or ammonium bicarbonate), maize (urea) and wheat (urea), respectively (Cai *et al.* 2002). Measurements in paddy soils (i.e., under flooded conditions) showed that NH_3 volatilization accounted for 27.6–59.7% of urea-N applied from different N fertilizers and application methods (Zhang *et al.* 2011). Ammonia losses from rice paddies were generally lower (13.2–31.1%) under different combined irrigation systems, including non-flooding and wet-dry cycles. The losses were also lower under different nutrient managements, including compound fertilizer treatment with ammonium bicarbonate or urea and/or control released urea (Xu *et al.* 2012). Limited studies have assessed NH_3 volatilization under upland farming (e.g., wheat, maize) in red soil. One of the studies reported NH_3 volatilization was in the range of 0.7–4.0% when 70–250 kg ha^{-1} urea was applied in red soil under upland farming with the crop rotation of smooth crabgrass (*Digitaria ischaemum*) in spring and winter radish (*Raphanus sativus*) in autumn (Zhou *et al.* 2007). These values were much lower than those from the calcareous soils in different regions and paddy soils in the same region. More accurate assessment on the NH_3 volatilization loss is needed from upland red soil.

In addition to NH_3, other volatile forms of N include nitrous oxide (N_2O), dinitrogen (N_2), and nitrogen oxides (NO_x, nitric oxide (NO) and nitrogen dioxide (NO_2)). N_2O is a potent greenhouse gas with the warming potential ~300 times greater than the equivalent mass of CO_2. It also contributes to the destruction of stratospheric ozone (Cicerone 1987). NO is a precursor of NO_2. It reacts with O_2 and further with water to form nitric acid (HNO_3), which is a major component of acid rain. The NO_x can also react with volatile organic compounds under sunlight to form ozone, a ground level air pollutant that is a respiratory hazard and a greenhouse gas (Williams *et al.* 1992). Understanding N loss in gaseous forms has significance in N cycling and developing management practices. More attention has been paid to NH_3 and N_2O because of their role in mass and global warming. The other forms of gaseous N are minor