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Nitrogen loss factors of nitrogen trace gas emissions and leaching from excreta patches in grassland ecosystems: A summary of available data

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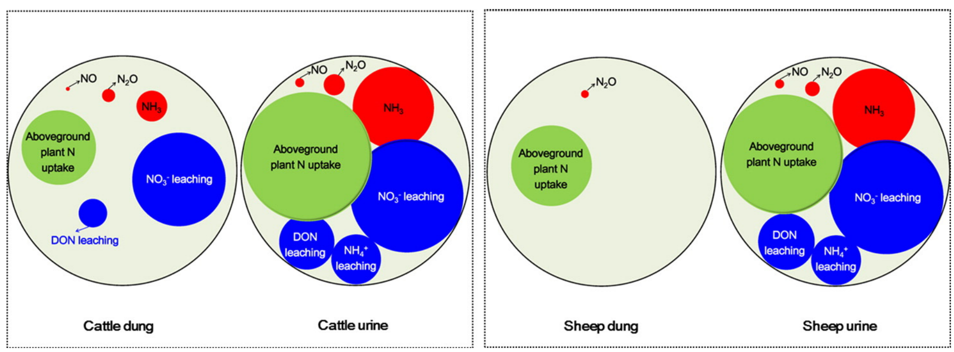
HIGHLIGHTS

- N_2O emission factors for excreta (0.08–0.35%) were lower than IPCC default value.
- NO and NH_3 losses were 0.01–0.12% and 1.69–12.7% of excreta N.
- NH_4^+, NO_3^-, and DON leaching were 0–4.58%, 16.4–24.6%, and 1.43–5.91%.
- Urine patches always caused more N losses or plant N uptake than dung patches.
- NO_3^- leaching was significantly negatively correlated with plant N uptake.

GRAPHICAL ABSTRACT



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ABSTRACT

Patches of excreta voided by grazing animals are nitrogen (N) transformation hotspots in grassland ecosystems and an important source of N trace gas emissions and leaching. Previous studies have focused on individual N losses from excreta, but no quantitative analysis has been performed on all the N losses *via* N trace gas emissions and leaching. To better understand the fate of N in excreta patches, we summarized 418, 15, 65, 22, 54, 11, and 81 measurements of nitrous oxide (N_2O), nitric oxide (NO), ammonia (NH_3), and ammonium (NH_4^+) leaching, nitrate (NO_3^-) leaching, dissolved organic nitrogen (DON) leaching, and aboveground plant N uptake, respectively. The results based on field studies indicated that the average fractions of N lost *via* N_2O were 0.28%, 0.76%, 0.08%, and 0.35% for cattle dung, cattle urine, sheep dung, and sheep urine, respectively. Only 0.01–0.12% of excreta N was lost *via* NO, whereas 1.69–12.7%, 0–4.58%, 16.4–24.6%, and 1.43–5.91% were lost by NH_3 and NH_4^+, NO_3^-, and DON leaching, respectively. Aboveground plant parts assimilated 10.4–31.4% of the excreta N. The N lost *via* N_2O from urine patches decreased as NH_3 losses increased, and greater NO_3^- leaching occurred with lower plant N uptake. The combined N_2O emission factors for dung and urine from cattle and sheep were 0.59% and 0.26%, respectively. Each N loss factor was much higher in urine patches than in dung patches, irrespective of animal type. This study provides general estimates of N losses and plant N uptake from excreta patches on grazed grassland based on currently available field data. More field studies are needed in the future with longer measurement periods from a wide range of climate zones to refine these N loss factors.

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1. Introduction

Nitrous oxide (N_2O), nitric oxide (NO), and ammonia (NH_3) are three key nitrogen (N) trace gases in the atmosphere. Nitrous oxide is one of the most powerful greenhouse gases and also the dominant anthropogenic substance contributing to stratospheric ozone (O_3) depletion (Ravishankara et al., 2009; IPCC, 2013). Nitric oxide contributes to the formation of tropospheric O_3 and acts as an important player in other photochemical reactions (Conrad, 1996). Ammonia plays an important role in neutralizing the acidity of atmospheric compounds, leading to the formation of inorganic aerosols, such as ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3), and it can also act as a precursor in the formation of fine particulate matter ($PM_{2.5}$) (Ellis et al., 2011; Schiferl et al., 2014). The losses of N_2O, NO, and NH_3 from agriculture are estimated to be 4.1 Tg N_2O-N year^{-1}, 3.7 Tg NO-N year^{-1}, and 30.4 Tg NH_3-N year^{-1} and contribute ~59%, ~10%, and ~76%, respectively, to total global anthropogenic emissions (IPCC, 2013). In addition to N trace gas losses, another major source of N loss from the soil-plant system is N leaching. Van Drecht et al. (2003) estimated that the total N (TN) leached from agriculture ecosystems into groundwater is 55 Tg N year^{-1} on a global scale.

Grasslands cover about 40% of global terrestrial ecosystems and support most of the world's grazing animals (Suttie et al., 2005). In grassland ecosystems, little of the N ingested by livestock is utilized, and approximately 75–95% of this N can be returned to the soil as excreta (urine and dung), where a greater proportion of the N is excreted in urine (Whitehead, 2000; Bell et al., 2015). The large amount of excreta N in relatively small patches usually exceeds the immediate plant requirements, so excreta patches are considered hotspots for N transformation and loss (Maljanen et al., 2007; Bertram et al., 2009). Nitrification and denitrification are the main pathways for N_2O and NO production in most soils, and denitrification can also be a sink for N_2O (Conrad, 1996). Ammonia volatilization from soils transports NH_3 from the surface of an ammoniacal solution to the atmosphere, where this process is driven by differences in NH_3 partial pressure (Bouwman et al., 2002a; Sommer et al., 2004). Nitrous oxide emissions are projected to increase by 29% from 2000 to 2050, mainly due to the increased application of N fertilizer and livestock production, and the increases in NO emission, NH_3 volatilization, and N leaching (together with N runoff) are projected to be 50%, 50%, and 19%, respectively (Bouwman et al., 2013).

A review by Oenema et al. (1997) based on field and laboratory data suggested a value of 2% for the N_2O emission factor for animal excreta, which was also proposed as a default value for calculating N_2O emissions from the N deposited by all grazing animals (IPCC, 2000). However, the IPCC (2006) also suggested the disaggregation of the default N_2O emission factor by animal type (2% for cattle and 1% for sheep). Moreover, some studies have suggested that the present IPCC default value overestimates N_2O emissions from excreta and the further disaggregated values have been proposed by excreta type (*e.g.*, Luo et al., 2013; Rochette et al., 2014; Saggar et al., 2015). The IPCC (1997, 2006) also proposed a default N loss fraction of excreta N for NH_3 volatilization + NO_x emission ($Frac_{GASM}$) of 20%, whereas that suggested for leaching and runoff ($Frac_{LEACH-(H)}$) was 30%. Bouwman et al. (2002b) suggested that the global annual NH_3 loss from animal manure in grasslands amounted to 23% of the N applied. However, the types of animal or excreta were not distinguished for these N loss factors. Many studies have been conducted to investigate the individual N loss factors from excreta, but no quantitative analysis has been performed of all the N loss factors *via* N trace gas emissions and leaching. In this study, we aimed to update the N loss factors from excreta by including recent literatures, as well as to investigate the potential relationships among N losses and plant uptake.

2. Materials and methods

2.1. Data collection

The databases were focused on N trace gas emissions, leaching, and uptake from patches of urine or dung (feces) deposited by grazing animals. Articles from peer-reviewed journals were retrieved from the Web of Science and Google Scholar using the keywords: "N_2O", "NO", "NH_3", "N leaching", or "N uptake" and "urine", or "dung" and "soil", or "grassland", with a cutoff date of January 30, 2016. Studies referring to the fate of N, as a percentage of the excreta N applied, were considered, including N losses as N_2O, NO, NH_3, NH_4^+ leaching, NO_3^- leaching, DON leaching and aboveground plant N uptake. For studies did not report the N fate as a percentage, the values were calculated as follows:

$$\text{N fate } (\%) = \{\text{N loss [or N uptake]}_{\text{excreta}} - (\text{N loss [or N uptake]}_{\text{control}}) / \ \text{N}_{\text{excreta}}\} \times 100$$

where N is that lost as either N_2O, NO, NH_3, NH_4^+ leaching, NO_3^- leaching, DON leaching, or N uptake; N loss [or N uptake]$_{excreta}$ and N loss [or N uptake]$_{control}$ are the data measured (kg N ha^{-1}) in the excreta patch and control plot, respectively, and $N_{excreta}$ is the amount of excreta N applied (kg N ha^{-1}).

The data compilations encompassed global grassland ecosystems with diverse grass species under different climate zones and managements using a range of methodologies to determine the fate of excreta N. Measurements of N_2O, N leaching, and N uptake collected over periods < 30 days were excluded, whereas all measurements of NO and NH_3 were included, due to the limited available data. The final dataset used for N_2O comprised 418 measurements from 89 studies, and there were 15 measurements from 7 studies for NO, 65 measurements from 25 studies for NH_3, 22 measurements from 9 studies for NH_4^+ leaching, 54 measurements from 21 studies for NO_3^- leaching, 13 measurements from 4 studies for DON leaching, and 81 measurements from 27 studies for N uptake (see the Supplemental material for details).

Studies were grouped into the following categories for analysis: 1) study type: laboratory studies (using sieved fresh or dry soil for incubation, as well as studies using pots or columns without plants under laboratory conditions), greenhouse studies (including experiments performed in pots or columns in a greenhouse with plants during the study), *in situ* field studies (field studies without soil destruction in local climates), and lysimeter studies (field studies using lysimeters); 2) excreta type: cattle (including dairy and non-dairy) dung, sheep (including sheep and goats; very limited data were available for goats, so they were included in the sheep category) dung, cattle urine, sheep urine, and artificial urine (an aqueous solution containing various nitrogenous compounds and salts to simulate the chemical properties of cattle or sheep urine); 3) the season of excreta application: spring (during March–May and September–November in the northern and southern hemispheres, respectively), summer (June–August and December–February in northern and southern hemispheres, respectively), autumn (September–November and March–May in northern and southern hemispheres, respectively), and winter (December–February and June–August in northern and southern hemispheres, respectively); 4) excreta N application rate: ≤400, 400–600, 600–1000, and >1000 kg N ha^{-1} (for urine, all urine types [cattle, sheep, and artificial urine] were used for the analysis of N application if not specified; note that the sheep urine N application rate was generally <600 kg N ha^{-1}); 5) length of measurement period: 30–90, 90–180, and >180 days; 6) soil texture type: coarse (including sand, loamy sand, sandy loam, loam, silt loam, and silt), medium (sandy clay loam, clay loam, and silty clay loam), fine (sandy clay, loamy clay, silty clay, and clay), and organic (mainly peat soil); 7) soil organic carbon (SOC) content: ≤4.0% and >4.0%; 8) soil TN content: ≤0.40% and >0.40%; 9) soil carbon-to-nitrogen ratio (C/N ratio): ≤12.0% and >12.0%; 10) soil pH: ≤5.0, 5.0–5.5, 5.5–6.0, and >6.0; 11) soil drainage: poor and well drained (soil drainage was included only when a description of soil drainage was reported in the literature). These 11 classes were all selected for the N_2O data summary for sheep dung, cattle dung, and urine patches. All urine studies were combined for the analysis of the final eight classes. Owing to a lack of published information and the