Seasonal and soil-type dependent emissions of nitrous oxide from irrigated desert soils amended with digested poultry manures

Roy Posmanik, Ali Nejidat⁎, Ofer Dahan, Amit Gross⁎

Department of Environmental Hydrology and Microbiology, Zuckerberg Institute for Water Research, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, 84990, Israel

HIGHLIGHTS

• Seasonal N₂O emissions from desert soils amended with digested manure are reported.
• Amended soils had substantially higher N₂O emissions compared to unamended soils.
• Winter emissions from amended loess were markedly higher compared to amended sand.
• Nitrification and denitrification have differentially contributed to N₂O emission.
• Lime treatment of digestate inhibited N₂O emissions regardless season or soil type.

A B S T R A C T

Expansion of dryland agriculture requires intensive supplement of organic fertilizers to improve the fertility of nutrient-poor desert soils. The environmental impact of organic supplements in hot desert climates is not well understood. We report on seasonal emissions of nitrous oxide (N₂O) from sand and loess soils, amended with limed and non-limed anaerobic digestate of poultry manure in the Israeli Negev desert. All amended soils had substantially higher N₂O emissions, particularly during winter applications, compared to unamended soils. Winter emissions from amended loess (10–175 mg N₂O m⁻² day⁻¹) were markedly higher than winter emissions from amended sand (2–7 mg N₂O m⁻² day⁻¹). Enumeration of marker genes for nitrification and denitrification suggested that both have contributed to N₂O emissions according to prevailing environmental conditions. Lime treatment of digested manure inhibited N₂O emissions regardless of season or soil type, thus reducing the environmental impact of amending desert soils with manure digestate.

1. Introduction

Organic soil amendments such as compost and digested manure are often used to improve soil fertility (Edmeades, 2003; Azeez and Van Averbeke, 2010). Among others, poultry manure that contains large amounts of organic matter (~85%) and N (3–4%) (Guerra-Rodríguez et al., 2001) is widely used as a soil amendment, as is or commonly after anaerobic digestion (Delgado et al., 2012; Kelleher et al., 2002).
However, even after anaerobic digestion, poultry manure applications to the soil might have negative environmental consequences, such as the introduction of various pollutants, pathogens and increased emissions of nitrous oxide (N₂O) (Ding et al., 2013; Nicholson et al., 2005; Posmanik et al., 2011). Addition of quicklime (CaO) towards the end of the digestion process has been suggested as an additional stabilization step to prevent sanitary problems and environmental contamination by digested poultry manure (Gross et al., 2012; Posmanik et al., 2011; Shargil et al., 2015).

Nitrous oxide is a potent greenhouse and ozone-scaping gas with a global warming potential 298 times greater than that of CO₂ (Czepiel et al., 1995; IPCC, 2014). Most N₂O emissions (70–80%) are attributed to microbial nitrification and denitrification and sourced mainly to agricultural practices (Butterbach-Bahl et al., 2013; Rollings et al., 2015). Under aerobic conditions, N₂O is produced mainly through the activity of ammonia-oxidizing microorganisms (Butterbach-Bahl et al., 2013; Stiegmeier et al., 2014), while under oxygen-limiting conditions, N₂O is produced mainly by denitrifying microorganisms (Harter et al., 2016; Snyder et al., 2009). In addition to microbial nitrification and denitrification, some fungi species also have the capability to produce N₂O through nitrate respiration under oxygen-limiting conditions (Takasaki et al., 2004; Tanimoto et al., 1992).

Due to a rapidly increasing world population, agricultural activity has been expanded to drylands to increase crop production for human consumption (Marasco et al., 2012). The scarcity of water, due to low precipitation inputs and high evaporation combined with nutrient-consumption (Marasco et al., 2012), is the temperature at depth z as a function of time t, $T_z(t) = T_0 + A_0 \sin(\omega t - \phi) e^{-z/d}$

(1)

where $T(z,t)$ is the temperature at depth z as a function of time t, $T_0$ is the average temperature, $A_0$ is the amplitude of the temperature at the surface, $\phi$ is the radian frequency, which is 2π times the actual frequency and normalizes the ‘clock time’ t to the sine wave period, and d is the ‘damping depth’, related to the specific thermal properties of the studied soil.

### 2.2. Experimental setup

Experiments were conducted at two separate but adjacent sites (<100 m apart). One site included native loess soil (72% sand, 16% silt, 12% clay) while the other included native sandy quartz soil (>99% sand). More details about these soils can be found elsewhere (Bruins, 1986; Evenari, 1982). Sites were not cultivated at least 3 years prior to the study and no crop was grown during the study. At each site, nine plots (1.5 m x 3 m) were marked. Drip irrigation was applied throughout the year (except on a few rainy days during the winter) at a daily rate of 20 m³ ha⁻¹ (irrigation was supplied in four pulses over 24 h). To eliminate any influence of plant and to avoid nutrient uptake by weeds, manual weeding was performed on a weekly basis. To monitor the subsurface parameters, a soil-profile-monitoring system (Dahan et al., 2013) was installed in each plot. The system included, time-domain reflectometer (TDR) sensors and ceramic suction cups at 30, 60 and 120 cm below the soil surface allowing water-content measurements and gas sampling. All sensors and samplers were installed prior to the beginning of the experiment using hand drilling. The ceramic cups were used for routine sampling of pore water. Soil-profile parameters, pore water and gas emission were sampled periodically as described below.

### 2.3. Manure amendments

Poultry manure taken from a local broiler farm was anaerobically digested in water at a 1:10 (w/w) ratio for 7 days following a typical digestion procedure (Gross et al., 2008). A portion of the resulted anaerobic digestate (AD) was collected and air-dried. The remainder was further stabilized by adding quicklime (CaO) at a concentration of ~10 g L⁻¹ slurry (Posmanik et al., 2011), mixing for 3 additional days and then air-drying the digestate. Three treatments were applied at each research site (sand/loess) in triplicate (overall, nine plots per site) as follows: (1) soil amended with AD; (2) soil amended with limed AD, and (3) control (soil with no amendments). All amendments were applied to the plots every 3 months for 24 months at a dose of 5 kg m⁻² following US Environmental Protection Agency regulations for land application of biosolids (USEPA, 1994), giving an annual loading of 50 g N m⁻². The chemical properties of the applied biosolids are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Digested poultry manure</th>
<th>Anaerobically digested</th>
<th>Anaerobically digested &amp; limed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>40.6 ± 0.4</td>
<td>33.7 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>Total Kjeldahl N</td>
<td>1.0 ± 0.06</td>
<td>0.9 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Inorganic N⁺</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Organic N</td>
<td>1.0 ± 0.06</td>
<td>0.9 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Organic C</td>
<td>15.3 ± 1.1</td>
<td>13 ± 0.9</td>
<td></td>
</tr>
<tr>
<td>C:N (−)</td>
<td>15.2 ± 0.06</td>
<td>14.4 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>8.4 ± 0.2</td>
<td>10.8 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>18.9 ± 2.1</td>
<td>22.5 ± 1.9</td>
<td></td>
</tr>
</tbody>
</table>

ND, not detected.

*Inorganic N = NH₄⁺ -N + NO₂⁻ -N + NO₃⁻ N.
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