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

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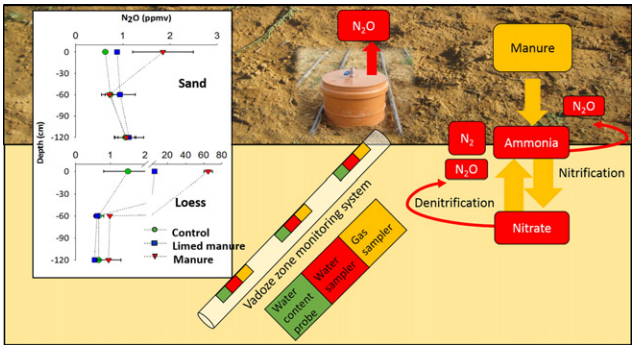
HIGHLIGHTS

- Seasonal N_2O emissions from desert soils amended with digested manure are reported.
- Amended soils had substantially higher N_2O emissions compared to unamended soils.
- Winter emissions from amended loess were markedly higher compered to amended sand.
- Nitrification and denitrification have differentially contributed to N_2O emission.
- Lime treatment of digestate inhibited N_2O emissions regardless season or soil type.

GRAPHICAL ABSTRACT



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ABSTRACT

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 (N_2O) 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 N_2O emissions, particularly during winter applications, compared to unammended soils. Winter emissions from amended loess (10–175 mg N_2O m^{-2} day^{-1}) were markedly higher than winter emissions from amended sand (2–7 mg N_2O m^{-2} day^{-1}). Enumeration of marker genes for nitrification and denitrification suggested that both have contributed to N_2O emissions according to prevailing environmental conditions. Lime treatment of digested manure inhibited N_2O 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).

Abbreviations: AD, anaerobic digestate; AOA, ammonia oxidizing archaea; AOB, ammonia oxidizing bacteria; AOP, ammonia-oxidation potential; EC, electrical conductivity; ECD, electron capture detector; TCD, thermal conductivity detector; TDR, time-domain reflectometer; TKN, total Kjeldahl nitrogen; WC, water content.

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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 (N_2O) (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-scavenging gas with a global warming potential 298 times greater than that of CO_2 (Czepiel et al., 1995; IPCC, 2014). Most N_2O emissions (70–80%) are attributed to microbial nitrification and denitrification and sourced mainly to agricultural practices (Butterbach-Bahl et al., 2013; Rowlings et al., 2015). Under aerobic conditions, N_2O is produced mainly through the activity of ammonia-oxidizing microorganisms (Butterbach-Bahl et al., 2013; Stieglmeier et al., 2014), while under oxygen-limiting conditions, N_2O 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 N_2O 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-poor soils, mainly N, limit primary production in drylands (Austin et al., 2004; Hooper and Johnson, 1999). Consequently, dryland agriculture depends strongly on irrigation and fertilization (Garcia-Gil et al., 2000; Segal et al., 2010; Shahid and Al-Shankiti, 2013). However, emission of N_2O from dryland agricultural soils has not received much attention (Barton et al., 2013a; Kidron et al., 2015), and there is a lack of information regarding the consequences of amending irrigated agricultural soils with poultry manure in hot arid regions on N_2O emissions.

In general, desert soils are alkaline with high salinity (Day and Ludeke, 1993) and are exposed to high radiation, together with extreme day/night and seasonal temperature fluctuations (Barton et al., 2013a; Walton et al., 2005). These extreme conditions impose great challenge on microbial activity and nutrient cycling (Schimel et al., 2007). Consequently, the objective of this study was to examine seasonal N_2O emissions from two nearby irrigated soil types (sand and loess) under arid conditions and in a controlled field experiment. It was hypothesized that the different water holding capacity of sand and loess would impact the nitrogen-transforming processes and consequently N_2O emissions.

2. Materials and methods

2.1. Study site

The research was conducted at the Ashalim agricultural experimental station in the central Negev Desert, Israel (30°58′55 N, 34°42′25E). The station is located on a natural border between sand and loess soils. Average ambient daily minimum winter temperatures are 5 ± 1 °C, typically ranging from 0.5–12 °C (December–March), and average ambient daily maximum summer temperatures are 36 ± 2 °C, typically ranging from 32 to 41 °C (June–September). The average annual rainfall is 90 mm (December–February) in a few rain events. Meteorological data were collected from a meteorological station located at the study site and operated by the Israeli Ministry of Agriculture. Surface soil temperature (Eq. (1)) was calculated from the available ambient and ground temperatures (0.5 m above ground and 0.1, 0.2 and 0.4 m below ground) using the following analytical model (Hillel, 1998):

$$T(z,t) = T_a + A_0 \sin\left(\omega t - {}^{z}/_{d}\right) e^{-{}^{z}/_{d}} \quad (1)$$

where $T(z,t)$ is the temperature at depth z as a function of time t, T_a is the average temperature, A_0 is the amplitude of the temperature at the surface, ω is the radial 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 × 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 m^3 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 1
Chemical properties of the applied anaerobically digested poultry manure. Values (percentage of dry weight, unless otherwise noted) represent average of six replicates ± SE.

Parameter	Digested poultry manure	
	Anaerobically digested	Anaerobically digested & limed
Organic matter	40.6 ± 0.4	33.7 ± 0.5
Total Kjeldahl N	1.0 ± 0.06	0.9 ± 0.03
Inorganic N[a]	ND	ND
Organic N	1.0 ± 0.06	0.9 ± 0.03
Organic C	15.3 ± 1.1	13 ± 0.9
C:N (−)	15.2 ± 0.06	14.4 ± 0.6
pH	8.4 ± 0.2	10.8 ± 0.6
EC (dS m^{-1})	18.9 ± 2.1	22.5 ± 1.9

ND, not detected.
[a] Inorganic N = NH_4^+-N + NO_2^--N + NO_3^- N.