



Effects of soil salinity and carbon availability from organic amendments on nitrous oxide emissions



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ABSTRACT

Soil salinity negatively affects the mineralization and nitrification processes of the N cycle and may also affect the production of nitrous oxide (N_2O) and N_2 to N_2O -N ratios. Application of organic amendments such as manures and composts improves soil physical, chemical, and biological properties of salt-affected soils. However, because these materials both mineralize N and serve as substrates for denitrifiers, they may also increase N_2O emissions. We studied the effect of organic amendments applied to saline soils on N_2O emissions and on N_2 to N_2O -N ratios. Saline soils with electrical conductivity (EC_e) measures of 2.8, 15.2, and 30.6 $dS\ m^{-1}$ were collected from Coachella Valley, California. Treatments included four organic amendments: active greenwaste compost (AGW), cured greenwaste compost (CGW), active dairy manure compost (ADM), and cured dairy manure compost (CDM). Treatments were incorporated at 50 $Mg\ ha^{-1}$ and incubated at 65% water-filled pore space (WFPS) for 60 days at 25 °C. Evolving carbon dioxide (CO_2 -C) and N_2O -N were monitored along with soil ammonium (NH_4^+ -N) and nitrate (NO_3^- -N) concentrations.

The results showed that increasing soil salinity increased cumulative N_2O -N losses but decreased CO_2 -C and N_2 emissions and N_2 to N_2O -N ratios. Of all the amendments, the highest cumulative N_2O -N and N_2 emissions were produced from the ADM treatment at all three salinity levels. In general, incorporation of active compared to cured amendments increased N_2 to N_2O -N ratios at all three salinity levels suggesting that applying active organic materials could be useful in mitigation of N_2O emissions from salt-affected soils under remediation.

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1. Introduction

Global warming and soil salinization are major international concerns. With an ever growing population, there is an increasing need to bring more agricultural land under production to feed people. Unfortunately development, erosion, and other pressures are reducing the earth's arable land (FAO, 2003). The problem is particularly acute in drylands where overgrazing and deforestation have led to salinization, associated problems of soil fertility, crusting, compaction, and widespread desertification (Dregne, 1983; Singh, 2009). It is estimated that more than 800 Mha of land is salt-affected globally (Martinez-Beltran and Manzur, 2005). Reclamation of salt-affected soils involves leaching after amending soils with organic materials such as manures and composts, or inorganic materials such as gypsum and sulfur. This removes salts and improves soil physical, chemical, and biological properties (Tejada et al., 2006). The extent of salinization and the rate of increase

in salt-affected lands make reclamation and maintenance of these soils an international priority.

Soil amendment use also affects the emission of nitrous oxide (N_2O), a potent gas that contributes to both global warming and ozone depletion. Nitrous oxide has been singled out as the most significant anthropogenic ozone depleting compound (Ravishankara et al., 2009). With an estimated 120-year global warming potential 310 times higher than carbon dioxide (CO_2), N_2O accounts for approximately four percent of United States greenhouse gas emissions (EPA, 2013). This high potency makes even relatively small changes in N_2O emissions potentially significant.

The production of N_2O from agricultural soils is primarily caused by microbially mediated nitrification and denitrification processes (Dobbie and Smith, 2001). Denitrification, which contributes both N_2O and N_2 , is promoted by anaerobic conditions and the presence of organic substrates for the denitrifiers. The rate of N_2O emission from soils is normally a function of soil moisture, temperature, and substrate supply (Schaufler et al., 2010); but under saline conditions the influence of salts on processes such as nitrification and denitrification should also be considered. It is also important to understand and relate the impact of applying N enriched degradable organic matter, such as manures and composts, on soil properties that influence N_2O production including the availability of C sources as substrates for denitrifying microorganisms (Meijide et al., 2007).

Abbreviations: AGW, active greenwaste compost; CGW, cured greenwaste compost; ADM, active dairy manure compost; CDM, cured dairy manure compost; WFPS, water-filled pore space.

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Many researchers have reported on the interaction between salt accumulation and soil microbial activity. Investigations have shown that saline conditions broadly suppress soil microbial communities and their biochemical activities (Rietz and Haynes, 2003; Yuan et al., 2007). Decreases in mineralization of organic C and N with increasing salt concentrations are well documented (Laura, 1974; McClung and Frankenberger, 1985; Pathak and Rao, 1998; Walpolo and Arunakumara, 2010) but specific information on the effects of saline soils amended with organic materials on CO₂, N₂O, and N₂ emissions is lacking. Typically, organic matter and microbial activity are concentrated in the top few centimeters of soil profile (Lavahun et al., 1996; Murphy et al., 1998). Hence, salinization near the soil surface is likely to affect many microbiologically mediated processes including the microbial production of N₂O in soils.

Given the interest in the use of organic amendments for remediating salt-affected soils, their effects on greenhouse gas emissions particularly N₂O, merits study. The objectives of this study were therefore:

- 1) To evaluate the effects of soil salinity on N₂O and CO₂ emissions and N₂ to N₂O–N ratios following the addition of organic amendments; and
- 2) To investigate the impact of labile carbon availability from active and cured organic amendments on the conversion of N₂O to N₂ gas.

2. Materials and methods

2.1. Site description and experimental treatments

Soils samples from three different salt-affected areas were collected from an abandoned field site in California's Coachella Valley (33° 35' 30.5" N, 116° 06' 20.7" W). The soils were characterized as fine-silty, mixed, superactive, calcareous, hyperthermic Aquic Torriorthents. The site had been fallowed for at least 5 years due to salinity issues. Samples from three areas with different EC_e properties (2.8, 15.2, and 30.6 dS m⁻¹) were collected from 0 to 15 cm depth, air-dried in the greenhouse to a gravimetric water content (θ_w) between 4–5%, and passed through a 2 mm sieve. Particle size analysis using hydrometer method (Gee and Bauder, 1986) for the three soils indicated that the soils were clay loam in texture. Physical and chemical characteristics of the three soils used in this study are given in Table 1.

Four organic amendments were considered as treatments in this study: active greenwaste (AGW), cured greenwaste compost (CGW), active dairy manure (ADM), and cured dairy manure compost (CDM). The greenwaste amendments were collected from a commercial greenwaste composting facility located in California. The AGW was comprised of plant material from local roadside cuttings and was collected from an actively managed two-week old turned windrow. The CGW was collected from a screened cured compost storage pile that had also undergone 10 weeks of active windrow composting. Treatments ADM and CDM

were collected from actively managed two-week old turned windrow and 12-week old on-farm compost storage piles, respectively, at a dairy farm in California. Samples of all treatments were air-dried in a greenhouse at 20 °C until moisture contents stabilized. The air-dried samples were then milled using a Wiley mill to pass through a 4 mm sieve. Chemical characteristics of treatments are presented in Table 2.

2.2. Incubation experiment

The three soils used in this study were pre-incubated at 40% WFPS in the dark at 24 ± 1 °C for two weeks prior to adding the organic amendments. The mass of water required to achieve the desired WFPS was calculated using the following equation (Hao et al., 2008):

$$\theta_g = \frac{\text{WFPS} \times \left(1 - \frac{\rho}{2.65}\right)}{\rho}$$

where WFPS is the fraction of total pore space filled with water (%), θ_g is the gravimetric soil water content at respective WFPS (g water g⁻¹ soil), ρ is the bulk density of the soil (g cm⁻³), and 2.65 is the soil particle density (g cm⁻³). During the course of incubation, containers were weighed periodically and water was added on a gravimetric basis to maintain the desired WFPS.

Separate experiments were setup to: 1) determine soil mineral N; and 2) monitor CO₂ and N₂O emissions from saline soils treated with organic amendments. Soil mineral N was studied in 1 L glass jars containing 250 g of air-dried soil while CO₂ and N₂O emissions were studied within 100 mL glass serum bottles containing 25 g of air-dried soil. All organic amendments (AGW, CGW, ADM, and CDM) were incorporated into the soil at an application rate of 50 Mg ha⁻¹ while control treatments received no organic amendment. The soil and amendments were mixed thoroughly and packed to achieve a bulk density of 1.25 g cm⁻³, a value similar to observed field conditions (Table 1). Soil moisture content was maintained at 65% WFPS as this has been shown to not only facilitate N mineralization and nitrification but also result in denitrification losses (Maag and Vinther, 1996). The 1 L jars were closed using lids with a 1 cm diameter hole in the center to facilitate aerobic conditions while limiting excessive soil moisture loss. Three replicates of each of the five treatments and three soil types were prepared for the 1 L jars while six replicates of the same were prepared for 100 mL serum bottles. Incubations were sustained for 60 days in the dark at 24 ± 1 °C to best represent mean daily temperatures in the arid and semi-arid regions such as California.

2.3. Soil and gas sampling procedures

Soil and gas samplings were conducted on days 0, 4, 7, 11, 15, 20, 25, 32, 37, 45, 53, and 60 days from the commencement of the incubations. Soil inorganic N concentration was determined by sub-sampling 3 g soil (dry weight) from each of the 1 L glass jars on the same day as the gas sampling. Each sub-sample was shaken with 2 M KCl (ratio 1:5) at 280 rpm for 1 h, centrifuged for 20 min at 1500 rpm, and then filtered through Whatman® no. 42 filter paper. Concentration of NH₄⁺-N and NO₃⁻-N were analyzed by using appropriate colorimetric methods (Maynard et al., 2008).

For the determination of CO₂ and N₂O emissions, 100 mL incubation serum bottles were flushed with ambient air for 30 s at a rate of 500 mL min⁻¹, which replaced the headspace air approximately three times to remove any traces of CO₂ and N₂O built-up previously and also to facilitate proper oxygenation of the environment. The bottles were then sealed with rubber septa and aluminum crimp seals for a period of 4 h. The production of N₂O and N₂ was determined using the acetylene (C₂H₂) block technique (Balderson et al., 1976). Of the six replicates prepared for each treatment, three replicates were injected with 8 mL of C₂H₂ (10% v/v) while the other three replicates did not

Table 1
Soil physical and chemical properties of top 0–15 cm soil layer.

| Parameter | Non-saline (S3) | Saline (S15) | Highly saline (S30) |
|--|--------------------|-----------------|------------------------|
| Sand (%) | 25.8 | 29.4 | 26.3 |
| Silt (%) | 40.0 | 32.5 | 37.2 |
| Clay (%) | 34.2 | 38.1 | 36.5 |
| Bulk density (g cm ⁻³) | 1.22 | 1.25 | 1.24 |
| EC _e (dS m ⁻¹) | 2.8 | 15.2 | 30.6 |
| pH | 7.86 | 7.32 | 7.91 |
| Total C (%) | 1.18 | 1.38 | 0.90 |
| Inorganic C (%) | 0.72 | 0.83 | 0.48 |
| Organic C (%) | 0.46 | 0.55 | 0.42 |
| Total N (%) | 0.12 | 0.13 | 0.08 |
| C:N | 10.19 | 10.49 | 15.48 |
| NO ₃ ⁻ -N (mg kg ⁻¹) | 180.18 | 175.15 | 177.39 |
| NH ₄ ⁺ -N (mg kg ⁻¹) | 2.80 | 2.47 | 2.18 |
| Inorganic N (mg kg ⁻¹) | 182.98 | 177.62 | 179.57 |

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