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Quantifying the effects of active and cured greenwaste and dairy manure application and temperature on carbon dioxide, nitrous oxide, and dinitrogen emissions from an extreme saline-sodic soil

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ABSTRACT

Amending saline-sodic soils with organic manures and composts can help to remediate them by improving their physical, chemical, and biological properties. Little is known as to how temperature effects organically amended saline-sodic soils in terms of soil nitrogen (N) dynamics, greenhouse gases, and dinitrogen (N_2) emissions, however. The effects of soil temperature and organic matter applications to a saline-sodic soil on CO_2, N_2O, and N_2 emissions were investigated. An extreme saline-sodic soil with electrical conductivity (EC_e) 100 dS m^{-1} and pH 7.8 was used in this study. Four organic amendment treatments were selected: active greenwaste (AGW), cured greenwaste compost (CGW), active dairy manure (ADM), and cured dairy manure compost (CDM). All treatments were incorporated at 100 Mg ha^{-1} and incubated at 70% water-filled pore space (WFPS) for 60 days at 15, 25, and 35 °C. Relative to 15 °C emissions, increasing soil temperatures significantly enhanced cumulative CO_2, N_2O, and N_2 losses from all treatments. The emissions of CO_2 increased in the AGW and ADM by 1.5 to 2.2 fold compared to CGW and CDM amended soils at all three temperatures. Higher cumulative N_2O-N emissions were released from ADM compared to AGW and CDM compared to CGW treatments at 25 and 35 °C, respectively. At 25 and 35 °C, AGW and CDM increased N_2 emissions relative to ADM and CGW, respectively. It was found that soil temperature had a significant effect on CO_2, N_2O, and N_2 emissions. However, CO_2 production highly correlated with N_2 emissions indicating that active organic materials could be carefully applied to remediate saline-sodic soils while mitigating N_2O emissions.

1. Introduction

Soil degradation due to salinization is one of the major causes for declining soil health and crop productivity throughout the world (Rengasamy, 2006). With nearly 1 billion ha representing about 7% of world's land surface affected by soil salinization (Metternicht and Zinck, 2003), reclamation of these soils to restore productivity has become an international priority. In arid and semi-arid regions such as California, low rainfall coupled with intense evaporation enhances salt accumulation in the upper soil profile. Elevated salt concentrations in soils may harm cultivated plants directly as a source of toxicity and due to osmotic imbalance, or indirectly, by damaging soil structure which can lead to soil water and air management problems (Tejada and Gonzalez, 2005; Wong et al., 2009). Sodium is particularly damaging and structural losses are common when exchangeable sodium percentages (ESP) exceed 15 (Qadir et al., 2006).

Because saline-sodic conditions hinder plant growth, such soils usually contain little organic matter. Organic matter additions can improve the structure of these soils by supporting microbial activity which in turn promotes the formation of the soil aggregates needed to facilitate remediation through leaching (Lakhdar et al., 2008). Organic amendments such as manures and composts are commonly used for this purpose (Abdel-Fattah, 2012; Liang et al., 2005; Tejada et al., 2006). Once incorporated, the amendments support many soil microorganisms including the nitrate denitrifiers responsible for most nitrous oxide (N_2O) emissions, a greenhouse gas of immense environmental interest (Ding, 2007; Huang et al., 2004). Nitrogen (N) mineralized from added organic amendments can also be converted from nitrite (NO_2^-) to N_2O by nitrifying denitrifiers (Wrage et al., 2001). Nitrous oxide is a potent greenhouse gas with a 100 year global warming potential (GWP_{100}) 298 times higher than carbon dioxide (CO_2) and is responsible for stratospheric ozone layer depletion (Myhre et al., 2013). Its atmospheric

Abbreviations: AGW, active greenwaste compost; CGW, cured greenwaste compost; ADM, active dairy manure compost; CDM, cured dairy manure compost

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concentrations have been rising since 1988 at a mean rate of 0.8 ppb yr^{-1}. Several studies have also reported the depletion of stratospheric ozone with increased N_2O concentrations (Portmann et al., 2012; Ravishankara et al., 2009; Revell et al., 2012; Wuebbles, 2009). Soils are identified as a major source of N_2O emissions with 6.0 Tg yr^{-1} emitted from natural soils and 4.2 Tg yr^{-1} from agricultural soils, accounting for nearly 70% of N_2O produced from the biosphere (IPCC, 2007). Enhanced denitrification rates with the application of organic matter to soils in the form of plant residues, green manures, and farm yard manures in the laboratory and field studies are well documented (Dalal et al., 2009; Ding, 2007; Meng et al., 2005; Velthof et al., 2002).

While generation of N_2O is of particular concern associated with using composts and manures to remediate saline-sodic soils, the significance of this point warrants further study. Nitrogen cycling is a biochemical process and soil conditions that affect soil microbiota may therefore increase or decrease N_2O production. Potentially significant factors include soil texture (Harrison-Kirk et al., 2013; Weitz et al., 2001), moisture (Schaufler et al., 2010; Schindlbacher et al., 2004; Zheng et al., 2000), temperature (Lai and Denton, 2017), pH (Rochester, 2003; Simek and Cooper, 2002), as well as the presence, forms, and characteristics of organic matter (Meijide et al., 2009; Subedi et al., 2016; Velthof et al., 2002).

Saline conditions also affect soil microbial population and their functions (Setia et al., 2010; Walpola and Arunakumara, 2010; Wong et al., 2008) often suppressing soil microbial communities and associated biochemical transformations (Rietz and Haynes, 2003; Yuan et al., 2007) including organic matter decomposition and nitrification (Beltrán-Hernández et al., 2007; Vega-Jarquin et al., 2003; Tejada et al., 2006; Walpola and Arunakumara, 2010). In a previous study of N_2O emissions following the use of compost to remediate saline soils at 25 °C, we found that, as the salinity (electrical conductivity of saturated soil-paste extracts, EC_e) of collected soils increased from 2.8 to 15.2 and 30.6 dS m^{-1}, N_2O-N losses were enhanced while CO_2 and N_2 emissions were reduced. Measured N_2 to N_2O-N ratios decreased as well which suggests that subsequent conversion of N_2O to harmless N_2 gas was reduced as salinity levels increased (Reddy and Crohn, 2014). This paper builds on that research by considering the effects of temperature on N_2O emissions after an extreme saline-sodic is amended with composts and manures.

Temperatures strongly affect microbial activity and thermal gradients, whether temporal or spatial, and can drastically affect C and N mineralization and denitrification processes. Warmer soil temperatures also accelerate N_2O emissions. For example, Szukics et al. (2010) showed increased nitrification and N_2O production with increasing temperatures from 5 to 25 °C under non-saline conditions. They concluded that increases in temperature accelerated the activity of both nitrifiers and denitrifiers resulting in greater nitrification rates and denitrification losses as N_2O under unsaturated (55% WFPS) conditions.

Heat may affect denitrifiers differently as they decompose available carbon under saline conditions. High temperature conditions coupled with high concentrations of salts in soil water are likely to impact the existing microbial community thereby affecting the decomposition of added organic amendments and denitrification (Conant et al., 2011; Mavi et al., 2012).

Information on the effect of reclaiming extreme saline-sodic soils using organic amendments at varying temperatures on N_2O and N_2 emissions is lacking however. Such information may support decisions as to appropriate consideration of elevation and aspect effects or identification of an environmentally optimal season selected for remediation efforts. There is a great potential for organic residuals to be used to improve the environment by remediating salt-affected soils (Lakhdar et al., 2010), but benefits will be further enhanced if conditions can be determined that minimize the generation of N_2O as improvements are made. This paper aims to evaluate the influence of temperature on CO_2, N_2O, and N_2 emissions within a saline-sodic soil environment amended with organic amendments representative of different waste materials and processing states. Following hypotheses were proposed:

1) high temperatures in organically amended saline-sodic soils accelerate microbial activity resulting in higher CO_2, N_2O, and N_2 emissions, and 2) increasing temperatures initially accelerates denitrification of N_2O to N_2 to a greater extent in active versus cured composts due to greater availability of labile C. These differences are reduced with time as labile materials are decomposed.

2. Materials and methods

2.1. Soil collection and characterization

Bulk soils were collected from the upper 10 cm of a fallow field located in San Jacinto, California (33° 50′ 44.2″N, 117° 1′ 39.6″W). Soils in this part of the field were abandoned for > 5 years due to their high salt content extending to a depth of 30 cm, consequently the soils were of poor soil structure and had impaired drainage. Taxonomically, these soils are classified as Grangeville coarse-loamy, mixed, superactive, thermic fluvaquentic haploxerolls (Web Soil Survey, 2011). The bulk soil samples were air-dried to 30% water holding capacity and sieved through a 2 mm sieve to achieve a uniform particle size. Subsamples were collected from bulk soils to determine their physical and chemical characteristics. Particle size analysis by hydrometer method revealed a loamy soil texture (Gee and Or, 2002). Both soil EC_e and pH were measured in saturated soil-paste extracts (Miller and Curtin, 2008) with a Con 6/TDS 6 meter developed by Oakton Instruments (Vernon Hills, Illinois, U.S.A.). Soluble cations were also measured on these extracts using Inductively Coupled Plasma Emission Spectroscopy, in order to determine their corresponding soil sodium adsorption ratio (SAR) values (Miller and Curtin, 2008). Total C and N contents were measured by subjecting soils to complete combustion using a NCS analyzer (Thermo Fisher Scientific Inc., Waltham, Massachusetts, U.S.A). Inorganic N contents were measured on 1:5 extracts obtained with 2 M KCl solution. Both nitrate (NO_3^-) and ammonium (NH_4^+)N were analyzed using segmented flow analysis method (Maynard et al., 2008) using AQ2 Discrete Analyzer (SEAL Analytical Inc., Wisconsin, U.S.A.). Important soil physical and chemical properties are presented in Table 1.

2.2. Treatments and characterization

Treatments included Control (no-amendment added) and four organic amendments: active greenwaste (AGW), cured greenwaste (CGW), active dairy manure (ADM), and cured dairy manure (CDM). Active and cured greenwaste materials were collected from a local commercial greenwaste composting facility in Southern California.

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

Parameter	Value
Sand (%)	43.12
Silt (%)	37.43
Clay (%)	19.45
Bulk density (g cm^{-3})	1.26
Calcium carbonate (%)	2.88
EC_e (dS m^{-1})	101.46
pH	8.24
SAR	149.75
Total C (%)	1.27
Total N (%)	0.08
C:N	15.53
NO_3^--N (mg kg^{-1})	205.57
NH_4^+-N (mg kg^{-1})	2.37