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Saline-Sodic Soils: Potential Sources of Nitrous Oxide and Carbon Dioxide Emissions?

Upasana GHOSH[1,*], Resham THAPA[1], Thomas DESUTTER[1], HE Yangbo[2] and Amitava CHATTERJEE[1]

[1] *Department of Soil Science, North Dakota State University, Fargo ND 58108 (USA)*
[2] *Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of the Yangtze River), Ministry of Agriculture, Huazhong Agricultural University, Wuhan 430070 (China)*

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ABSTRACT

Increasing salt-affected agricultural land due to low precipitation, high surface evaporation, irrigation with saline water, and poor cultural practices has triggered the interest to understand the influence of salt on nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions from soil. Three soils with varying electrical conductivity of saturated paste extract (EC_e) (0.44–7.20 dS m^{-1}) and sodium adsorption ratio of saturated paste extract (SAR_e) (1.0–27.7), two saline-sodic soils (S2 and S3) and a non-saline, non-sodic soil (S1), were incubated at moisture levels of 40%, 60%, and 80% water-filled pore space (WFPS) for 30 d, with or without nitrogen (N) fertilizer addition (urea at 525 µg g^{-1} soil). Evolving CO_2 and N_2O were estimated by analyzing the collected gas samples during the incubation period. Across all moisture and N levels, the cumulative N_2O emissions increased significantly by 39.8% and 42.4% in S2 and S3, respectively, compared to S1. The cumulative CO_2 emission from the three soils did not differ significantly as a result of the complex interactions of salinity and sodicity. Moisture had no significant effect on N_2O emissions, but cumulative CO_2 emissions increased significantly with an increase in moisture. Addition of N significantly increased cumulative N_2O and CO_2 emissions. These showed that saline-sodic soils can be a significant contributor of N_2O to the environment compared to non-saline, non-sodic soils. The application of N fertilizer, irrigation, and precipitation may potentially increase greenhouse gas (N_2O and CO_2) releases from saline-sodic soils.

Key Words: CO_2, electrical conductivity, greenhouse gas emission, moisture, N fertilizer application, N_2O, salinity, sodicity, sodium adsorption ratio

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INTRODUCTION

Soil salinization is considered to be one of the most important chemical processes causing land degradation and desertification (UNEP, 1991). Internationally, 397 and 434 million ha of soils are reported as being saline and sodic, respectively (FAO, 2015). Soils with electrical conductivity (EC) of saturated paste extract (EC_e) > 4.0 dS m^{-1} are characterized as saline, sodic soils having a high percentage of sodium (Na) in solution phase (sodium adsorption ratio (SAR) of saturated paste extract (SAR_e) > 13), and soils having both high EC and high SAR ($EC_e > 4.0$ dS m^{-1} and $SAR_e > 13$) are characterized as saline-sodic soils (Sumner *et al.*, 1998). Land degradation and poor crop yield due to soil salinity and sodicity have become a serious challenge to the growers of the Northern Great Plains, USA (Hadrich, 2011). The excess salt in soil interferes with the normal soil processes and thus affects the nutrient uptake by crop, which results in poor crop yield and inhibited plant growth (Bernstein *et al.*, 1966; Nelson and Ham, 2000). Increase in Na concentration in soil, or increased sodicity, causes severe nutrient imbalances in plant tissues (Agarwal *et al.*, 1964; Moustafa *et al.*, 1966). Liu *et al.* (2000) reported significant grain yield reduction of wheat (*Triticum aestivum* L.) in a sodic soil due to both soil physical and nutritional changes.

Agricultural practices, especially irrigation and fertilization, intended to increase crop yield can also increase salinity, which in turn reduces agricultural production and balance of ecosystems (Neumann, 1997; Rengasamy, 2006). Considering the current situation regarding agricultural practices and soil degradation, Wong *et al.* (2008) suggested a high potential of increase in secondary soil salinization and sodification, especially in the areas with high concentration of Na salts in the soil profile. In last few decades, land degradation due to salinity and sodicity has increased consi-

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[*] Corresponding author. E-mail: upasana.ghosh@ndsu.edu.

derably in Yellow River Basin of China and Aral Sea basin in Central Asia (Cai *et al.*, 2003; Gupta and Abrol, 2000).

Apart from yield reduction, excess salts interferes with the microbial activity and thus microbe-mediated soil processes are also affected (Liang *et al.*, 2005; Tejada *et al.*, 2006). The microbial biomass is not only an important labile fraction of the soil organic matter, but also a source of nutrients and soil enzymes (De Souza Silva and Fay, 2012). High concentration of salt in soil affects microbial respiration (Laura, 1976; Pathak and Rao, 1998) and causes increases or decreases in carbon (C) and nitrogen (N) mineralization (Pathak and Rao, 1998; Wichern *et al.*, 2006). Rietz and Haynes (2003) showed that increases in soil salinity and sodicity resulted in a smaller, more stressed, and less metabolically active microbial community. However, according to Oren (2001) and Hagemann (2011), although sensitive microbial cells degenerate due to high osmotic potential, some microorganisms can adapt to the environment of increased salt concentration and they need much more energy to regenerate cell walls and to synthesize osmolytes to combat the adverse effect of salts. As salinity is considered a stress to soil microorganisms, Rietz and Hayne (2003) found that organic matter decomposition was inhibited by increasing salinity which might cause a substantial decline in potentially mineralized N. However, Khoi *et al.* (2006) found that adverse effects of salinity on N mineralization were short-lived and the rate of N mineralization was recovered at later stages.

Soil nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions are greatly driven by microbial activities, *i.e.*, denitrification and metabolism (Frankenberger and Bingham, 1982, Matteuci *et al.*, 2000). Salt concentrations may have significant effects on N_2O and CO_2 emissions (Setia *et al.*, 2011). Oren (1999) reported that denitrification prevailed at or close to sodium chloride (NaCl) saturation in the presence of halophilic microorganisms, which may result in considerable amounts of N_2O emission from salt-affected soils. Degree of salt saturation depends on soil moisture (Rabie *et al.*, 1985), which continuously changes with rainfall, evaporation, irrigation, and drainage. Due to poor productivity of salt-affected soils, N fertilizers are often added at high rates to increase yield, but simultaneous applications of N fertilizer and poor quality irrigation may also cause increased accumulation of soluble salts (Rietz and Haynes, 2003; Han *et al.*, 2015). Many studies (Qian *et al.*, 1997; Kessavalou *et al.*, 1998; Sehy *et al.*, 2003) observed that soil N_2O emissions increase significantly as soil moisture exceeds 60% water-filled pore space (WFPS) and that soil mineral N increases with fertilization.

For better management of soils and environment, it is necessary to understand the effect of the complex interaction of different components of the soil environment on the greenhouse gas emissions. Laboratory incubation of soil samples and gas efflux measurements offer an opportunity to separate out the effects of different soil factors on CO_2 and N_2O emissions. The primary objective of this study was to investigate the effects of soil salinity and sodicity, moisture, and N application on N_2O and CO_2 emissions, in order to provide a tool to model CO_2 and N_2O emissions from saline-sodic soils.

MATERIALS AND METHODS

Soils

Using a tilling spade, soil samples (0–30 cm) were collected from three different sites within a salt-affected agricultural area located in Richland County, North Dakota, USA (46°16.917′ N, 97°15.488′ W) and labelled as S1, S2, and S3. The sampled soils are fine, smectitic, frigid Leptic Natrusolls (Exline series) (USDA Classification System), which are a common natric soil in the study area. Soil samples were air dried, ground to pass through 2.0-mm sieves and analyzed for EC_e, SAR_e, pH of saturated paste extract (pH_e), texture (Bouyoucos, 1962), cation exchange capacity (CEC) (Chapman, 1965), available N (Karla and Manyard, 1993), organic matter (Nelson and Somners, 1996), and moisture at field capacity and permanent wilting point (Klute, 1986) (Table I). Although all samples were taken within the same soil mapping unit, they ranged from non-saline, non-sodic to saline-sodic soils, with varying EC_e (0.44, 7.20, and 4.55 dS m^{-1} for S1, S2, and S3, respectively) and SAR_e (1.0, 27.7, and 14.7 for S1, S2, and S3, respectively), which is typical of sodic landscape in the study area. Selected physical and chemical characteristics of the soils are provided in Table I.

Incubation and sample analysis

The processed soils (S1, S2, and S3) 200 g each were weighed into 1.0 L air-tight glass jars, compacted to a specific depth to obtain a bulk density of 1.29 g cm^{-3} and incubated at 40% WFPS for 3 d to equilibrate. After that, the soils were maintained at 40%, 60%, or 80% WFPS. At Each moisture level, the soil was treated with four uniform urea (460 g N kg^{-1}) granules (525 µg g^{-1} soil) placed evenly on the surface, with zero N (no-urea) addition as a control. The