Geoderma 332 (2018) 109–120

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Co-effects of salinity and moisture on CO_2 and N_2O emissions of laboratory-incubated salt-affected soils from different vegetation types

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ARTICLE INFO

Handling Editor: M. Vepraskas

Keywords:
Greenhouse gas
Carbon dioxide
Nitrous oxide
Salt-affected soil
Yellow River Delta

ABSTRACT

The temporal variation of precipitation and relevant salinity fluctuation can significantly affect greenhouse gas (GHG) emissions of salt-affected soils in the Yellow River Delta (YRD) of China. The current study aims to investigate the effects of salinity and moisture on CO_2 and N_2O emissions of saline soils. Soils collected from different vegetation communities were incubated in glass Mason jars under treatment of different levels of salinity and moisture. Gas samples were collected from the headspace of jars and analyzed using gas chromatography during the incubation period. Soil CO_2 and N_2O emission rates decreased steadily over time, and then were relatively stable during the final incubation. Cumulative CO_2 and N_2O emissions increased steadily across the incubation period in all treatments. However, cumulative N_2O emissions in bare land with no vegetation cover decreased steadily. In general, production rate and cumulative emission of CO_2 were highest in herbage communities, were intermediate in woody community, and were lowest in bare land under all treatments. The negative relationship between cumulative GHG emission and soil salinity was more significant in soils that contained low levels of salt, than that in other soils. The significant positive correlation between cumulative GHG emissions and soil moisture was found in all soils. The effects of salinity on GHG emission were stronger in soils with low levels of salt. Compared with soils collected from bare land with no vegetation cover, soils from different vegetation communities emitted more CO_2 and N_2O. Perhaps more attention, therefore, should be paid to pulse emissions of GHG as a result of destruction of vegetation in the course of exploitation and utilization of saline soil resources.

1. Introduction

Soil salinization is considered to be one of the most common land degradation processes. There are about 831 million ha (> 6%) of salt-affected agricultural land worldwide (Amini et al., 2016), with 397 million ha of saline soils and 434 million ha of sodic soils (FAO, 2015). Soils that contain excess salts not only interfere with the normal soil processes, but also affect the nutrient and water uptake by plant, which impair plant growth (Nelson and Ham, 2000).

Excess salts affect the microbial activity, apart from plant growth inhibition, and interferes with microbe-mediated soil processes (Liang et al., 2005; Tejada et al., 2006). Soil carbon (C) and nitrogen (N) mineralization increases or decreases following varied microbial respiration, which was affected by high concentration of salt (Pathak and Rao, 1998; Wichern et al., 2006). As a stress to soil microorganisms, increasing salinity inhibits organic matter decomposition and causes a decline of N mineralization (Rietz and Haynes, 2003). However, Khoi et al. (Khoi et al., 2006) found that N mineralization rate was inhibited temporarily and recovered at later stages. Many factors, such as soil types and incubation conditions, could be responsible for the differences.

Carbon dioxide (CO_2) and nitrous oxide (N_2O), two major radioactively active greenhouse gases (GHG) contributing to global warming, were driven by microbial activities, such as denitrification and metabolism, and may be significantly affected by salt and moisture conditions (Houska et al., 2017; Maucieri et al., 2017; Setia et al., 2011b; Shi

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https://doi.org/10.1016/j.geoderma.2018.06.025
Received 15 April 2018; Received in revised form 22 June 2018; Accepted 30 June 2018

Table 1
Soil properties (means ± standard deviation) before the incubation.

Soil types	pH	EC (mS cm^{-1})	WHC (g g^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^-N (mg kg^{-1})	TOC (g kg^{-1})	TN (g kg^{-1})
BL	7.78 ± 0.05	14.84 ± 1.21	0.36 ± 0.01	4.50 ± 0.35	11.87 ± 0.83	7.52 ± 0.81	0.35 ± 0.02
TC	7.62 ± 0.03	10.46 ± 1.02	0.41 ± 0.01	4.09 ± 0.38	10.24 ± 0.78	8.83 ± 0.77	0.46 ± 0.01
SS	7.41 ± 0.03	5.18 ± 0.37	0.50 ± 0.01	4.30 ± 0.29	7.71 ± 0.49	9.33 ± 0.79	0.83 ± 0.02
PA	7.36 ± 0.02	2.47 ± 0.22	0.53 ± 0.01	5.09 ± 0.41	3.90 ± 0.27	11.78 ± 0.86	1.05 ± 0.08

BL, bare land; TC, *Tamarix chinensis*; SS, *Suaeda salsa*; PA, *Phragmites australis*.

et al., 2015). In general, severe drying and excess salt limit microbial activity by osmotic stress (Smith et al., 2003; Stark and Firestone, 1995; Yemadje et al., 2016), and soil aeration can be limited with increasing levels of water (Mentges et al., 2016; Yuste et al., 2017). Zhang et al. (2016) and Oren (1999) reported that considerable amounts of N_2O emitted from salt-affected soils result from prevailed denitrification. Similarly, C mineralization has also been reported to increase with increasing salinity (Marton et al., 2012). However, Kontopoulou et al. (2015) found that salinity has no significant effect on CO_2 and N_2O productions. Many studies (Kessavalou et al., 1998; Qian et al., 1997; Schaufler et al., 2010; Sehy et al., 2003) showed that emission of soil N_2O increase significantly along a soil moisture gradient, but CO_2 production is highest at an intermediate soil moisture. Salinity is usually determined by changed moisture of soil resulting from rainfall, evaporation, irrigation, and drainage (Ghosh et al., 2017; Rabie et al., 1985). Therefore, GHG production of salt- affected soil could be affected by the interactive effect of salinity and moisture.

The Yellow River Delta (YRD), one of the three biggest deltas in China, is the fastest growing delta and the most active land–ocean interaction regions among the large river deltas in the world (Wang et al., 2012). Due to its great exploitation potential, the YRD is called as the "Golden Triangle" and gets more and more attention. However, rainfall in this area is scarce and irregular, with about 70% of precipitation occurring between June and August, and excessive salt exists in underground water. These conditions cause soil salinization and alkalization, leaving only a few tolerant plant species, thus reducing plant diversity. *Tamarix chinensis*, *Suaeda salsa* and *Phragmites australis* is three dominant plant species adapt the saline-alkaline habitat in this region. Since vegetation plays an important role in regulating the temporal and spatial variations of soil respiration by controlling a variety of environmental variables (Barba et al., 2013; Han et al., 2014; Jenkins and Adams, 2010). Zhang et al. (2013, 2015) and Song et al. (2013) investigated GHG production of saline soils in above-mentioned three vegetation communities and in bare land with no vegetation cover in situ. They found that temporal variations of GHG emissions were related to the interactions of abiotic factors, such as soil water content and electrical conductivity, while spatial variations were mainly affected by the vegetation composition at spatial scale. Exploring the complex interaction among different environmental factors on GHG emission is necessary for better management of soil and environment. Measurement of soil gas production under laboratory-controlled conditions offer an opportunity to understand the effects of specific factors on CO_2 and N_2O emissions (Ghosh et al., 2017).

To our knowledge, even though variations in soil salinity and moisture are considered as the main driver of GHG emission very few studies have been conducted to investigate the effects of salinity and moisture on CO_2 and N_2O emissions of saline soils under different vegetation types. In this laboratory incubation study, therefore, we sought to examine the effects of salinity, moisture, and their interaction on CO_2 and N_2O emissions of salt-affected soils collected in bare land (BL) and three adjacent vegetation communities, *Tamarix chinensis* (TC), *Suaeda salsa* (SS) and *Phragmites australis* (PA). The objectives of the current study were to assess the effects of soil salinity and moisture on CO_2 and N_2O emissions, and compare the difference of CO_2 and N_2O emissions among soils collected from different vegetation communities.

2. Materials and methods

2.1. Soil sampling

Soil samples were collected from saline-alkaline soil with no vegetation cover (i.e. bare land BL), with *T. chinensis* community (TC), with *S. salsa* community (SS) and with *P. australis* community (PA), which are located in the Nature Reserve of the Yellow River Delta (37°35′–38°12′N, 118°33′–119°20′E) in Dongying City, Shandong Province, China. Samples from four areas were collected from 0 to 10 cm depth, air-dried at room temperature and passed through a 2-mm stainless steel sieve. Soil characteristics are shown in Table 1.

2.2. Experimental design and set-up

We used a 4 × 3 factorial design with the following main factors: 1) salinity as the main factor (control or 1 mg/g, 3 mg/g and 5 mg/g, represented by S1, S2, S3 and S4, respectively); 2) moisture as a secondary factor (40%, 70% and 130% water-holding capacity (WHC), represented by W1, W2 and W3, respectively). Therefore, there were 12 treatment combinations in the present experiment, each with three replicates. At the beginning of experiment, 80 g of air-dried soil was put into a 1-L glass Mason jar. Soil salinity was adjusted using deionized and sea water to ensure the salt types were similar with those in field soil. The deionized or salinized water was used to adjust soil moisture. The incubation began when water content of all soils reached to required levels. The jars were kept at 25 ± 1 °C during the entire incubation period, and were weighed daily to correct the soil moisture by adding deionized water onto the soil surface.

2.3. Greenhouse gas measurements

Gas samples were collected and measured after 1, 2, 4, 7, 10, 15, 20, 27, 37 and 52 days of incubation according to a procedure similar to that described by McDaniel et al. (2014) and Sun et al. (2014). Jars were thoroughly flushed with fresh air using an air compressor for 5 min to ventilate air in all jars, they were sealed with gas tight lids equipped with three-way valve to allow collection of CO_2 and N_2O samples from the headspace. Gas samples were immediately collected via syringe and injected into 20-ml pre-evacuated dark cool packs. Soils were subsequently incubated for 24 h before a second gas sample was collected. After that, the jars were opened until the next sampling date. Packs were analyzed for greenhouse gases content within 24 h of gas sampling using gas chromatography (Agilent 7890A) equipped with FID and ECD. Soil GHG production rate was calculated as the difference in CO_2 and N_2O concentrations between the two sampling time points (McDaniel et al., 2014). Production rates of CO_2 and N_2O were measured more frequently at the beginning of the incubation and less frequently toward the end of the experiment during the study.

The emission rate (F) of CO_2 (mg CO_2 kg soil^{-1} d^{-1}) or N_2O (μg N_2O kg soil^{-1} d^{-1}) was calculated by the following equation (Sun et al., 2014):

$$F = \rho \times \frac{V}{M} \times \frac{dc}{dt} \times \frac{273}{T}$$

where ρ is the density of CO_2 or N_2O in standard temperature and