Soil & Tillage Research 168 (2017) 33–41

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Effects of application of microbial fertilizer on aggregation and aggregate-associated carbon in saline soils

Peifei Cong[a,b], Zhu Ouyang[a,*], Ruixing Hou[a], Daorui Han[a,b]

[a] Yucheng Comprehensive Experiment Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 20 July 2016
Received in revised form 5 December 2016
Accepted 7 December 2016
Available online 27 December 2016

Keywords:
Aggregates
Soil organic C
Saline soil

ABSTRACT

A pot experiment was conducted to elucidate the process of aggregate formation and the accumulation of soil organic C as affected by application of microbial fertilizer in coastal saline soils east of Shandong Province, China. The study was designed with five levels of electrical conductivity (EC): 0.33, 0.62, 1.13, 1.45 and 2.04 ds m^{-1}. For each EC level, a treatment group received microbial fertilizer (MF) and a control (CK) did not. The mass and organic C concentration of aggregates (>2000 μm large macroaggregate, 250–2000 μm small macroaggregate and 53–250 μm microaggregate, <53 μm silt + clay fraction) were measured. Treatments and controls were denoted as MF_1–MF_5 and CK_1–CK_5 from lowest to highest EC values. The soil organic C concentrations of MF_1–MF_3, but not MF_4 and MF_5, were significantly higher than that of their controls. For MF_1–MF_3, application of microbial fertilizer significantly increased the proportion of macroaggregates. MF_1–MF_3 treatments exhibited significantly increased organic C concentration in the large macro-aggregates and free silt + clay fractions, but the differences were not significant for EC values of 1.45 and 2.04 ds m^{-1}. The mass proportion of large and small macroaggregates was significantly related with organic C concentration in the microaggregates. For EC values 1.45 and 2.04 ds m^{-1}, the silt C was too low to form the microaggregates, and the aggregates were not significantly different. Significant linear relationships existed between the organic C concentration in the silt + clay fraction and mass ratio of the macro- to micro-aggregates. We suggested that microbial fertilizer reduced the silt + clay fraction and increased the microaggregate mass by increasing soil organic C in the silt + clay fraction, which promoted the formation of macroaggregates. The mass and organic C of microaggregates played an important role in aggregation and C accumulation.

1. Introduction

Soil salinity is a major threat to the productivity of agricultural land (Sumner, 1995). Seawater encroachment and irrigation with saline water combined with high evapotranspiration continually intensifies the salinization problem in coastal soils (Rousk et al., 2011a). The Yellow River Delta is east of the Shandong Province in China. Currently, the area consists of 1.3×10^5 km^2 of salt-affected coastal lands in China (Qin et al., 2002). Salinization negatively affects agricultural productivity, environment health, and economic welfare (Rengasamy, 2006). Bioremediation might provide an effective and economical method to ameliorate saline soil. However, most studies concerning the improvement of saline soils concentrated on salt-tolerant plants. Mishra et al. (2002) and Singh et al. (2011) have concluded that afforestation, specifically factors such as tree species, community composition, and age and productivity of the forest, could induce substantial changes in soil properties during restoration of degraded sodic lands. Kursakova (2006) revealed that artificially sown perennial herbs had a pronounced effect on soil desalinization in the Altai region. Zhang et al. (2014) confirmed that inoculation of the rhizosphere of castor beans with fungi could ameliorate coastal saline soil. In recent years, studies on the impact of microorganism on the saline soil (Fernández-Luqueño et al., 2008) have started to emerge, together with studies of the influence of salinity on the concentration of soil microbial biomass (Egamberdieva et al., 2010) and composition (Wichern et al., 2006). However, there are still many problems on the mediated processes in the saline soil using the fertilizer with microorganisms, especially on soil organic carbon accumulation. Soil organic C is a measure of a soil"s health.

* Corresponding author.
E-mail addresses: ouyangzhu2016@outlook.com, ouyz@igsnrr.ac.cn (Z. Ouyang).

http://dx.doi.org/10.1016/j.still.2016.12.005
0167-1987/

The effects of salinity and sodicity on plant health adversely impacts upon SOC stocks in salt-affected areas, generally leading to less SOC (Wong et al., 2010). Lugato et al. (2010) found that soil organic C concentration enhanced, along with the macroaggregation promoting. Soil organic C in macroaggregates was stable because of the physical protection of particulate matter (Kong et al., 2005). Mikha and Rice (2004) reported that improving macroaggregation and aggregate-associated organic C in the intra-particulate organic matter (iPOM) subfraction increased soil organic C. However, some recent researches have suggested that the increase of soil organic C in aggregates mainly accumulated in silt + clay sub-fraction (Liao et al., 2006 Schwendenmann and Pendall, 2006). In the saline soil, after application of microbial fertilizer, the relationship between the aggregate and soil organic C is ambiguous.

Sodicity alters soil physical properties, due to the increase of swelling, dispersion and slaking upon wetting (Wong et al., 2010). Those adversely effects caused a decline in soil structure. And then, the growth of plant had subjected to environment factors in stress. Furthermore, saline and sodic soil impact upon soil nutrient cycling and supply. Despite this, soil microorganisms have the ability to adapt to or tolerate osmotic stress caused by salinity and confronted with such conditions (Sparling et al., 1989). Casamayor et al. (2002) also reported microbes could thrive in strongly saline soil. Thus, we attempted to use microbial fertilizer to ameliorate saline soil.

Aggregates are important components of soil structure. Tisdall (1994) found soil microorganisms, especially fungi, may play an important role in the formation and stabilization of macro-aggregates. Besides the physical effects of enmeshment by hyphal, hyphae could enwind some hyphae could produce extracelluar polysaccharides to bind microaggretes into microaggreages (Tisdall, 1994 Tisdall and Oades, 1982). Guggenberger et al. (1999) provide evidence that microhabitats enriched in substrate acted as 'hot spots' for fungal growth and macroaggregation.

Killham (1994) describes two main adaptation strategies of microorganisms to salinity stress, one adaptation mechanism of the cell is to selectively absorb ions necessary for metabolism (e.g. NH_4^+) instead of the incorporated solute, such as Na^+, Cl^-. The other is to antagonize the concentration gradient between soil solution and cell cytoplasm by producing organic compounds. However, these mechanisms are known from a certain salt concentration range but have hardly ever been studied on differences in microorganism salt tolerance across the soil salinity gradient. Furthermore, these mechanisms are obtained from single microorganisms, because it was difficult to study on a community level. We attempted that using the soil aggregate and organic C fractions to explore the effectiveness and mechanism of microbial fertilizer application to ameliorate adverse effects across the soil salinity gradient.

A pot experiment was conducted in a greenhouse to elucidate the process of aggregate formation and the accumulation of soil organic C as affected by application of microbial fertilizer. In the present study, we used agricultural soils from the Yellow River Delta representing a range of soil salinities. We wanted to (1) evaluate the influence of microbial fertilizer application on organic C and aggregate-associated C at different salt concentration levels, and (2) explore the processes of organic C accumulation within saline soils. We hypothesized that microbial fertilizer application would improve saline soil structure by increasing soil organic C and improving macroaggregation and aggregate-associated organic C in the iPOM fraction.

2. Material and methods

2.1. Soil

Five soils with similar texture (loam) were collected from Wudi County in the Shandong Province, China (37.73N, 117.6E) on April 22, 2015 at 0–20 cm depth. Seawater encroachment and irrigation with saline water intensifies the salinization problem in coastal soils (Hu et al., 2016). The salt was dominantly NaCl (Yang et al., 2014). Their original electrical conductivity (EC) was 0.33, 0.62, 1.13, 1.45, and 2.04 ds m^{-1} (hereafter referred to soils A–E, Table 1). This range was chosen based on previous studies (Chowdhury et al., 2011; Mavi et al., 2012). Before the experiment, in order to activate the soil microbes and stabilize their activity, the air-dry soils were pre-incubated for 10 days at 50% of water holding capacity (WHC) (Setia et al., 2011). After pre-incubation, 8 kg soil was placed into pots (diameter 24 cm, height 20 cm) with a nylon mesh base. The soils were packed according to the bulk density in the field by adjusting the height of the soils in the cores to achieve the desired volume (Yan and Marschner, 2013).

2.2. Experimental design

We used spring maize in our experiment. A glasshouse experiment was conducted with a completely randomized block

Table 1
Soil characteristics.

Parameter	Soil A	Soil B	Soil C	Soil D	Soil E
$EC_{1:5}$ (ds m^{-1})	0.33	0.62	1.13	1.45	2.04
EC_e (ds m^{-1})	10.6 ± 0.6	13.8 ± 3.8	19.6 ± 9.6	23.2 ± 0.26	29.9 ± 9.9
Sand (%)	43	49	47	47	45
Silt (%)	37	34	35	36	35
Clay (%)	20	17	18	17	20
Water holding capacity (%)	29	30	32	33	35
pH	8.84 ± 0.06	8.80 ± 0.05	8.94 ± 0.06	8.97 ± 0.07	9.00 ± 0.04
Total organic carbon (%)	0.66 ± 0.02	0.56 ± 0.01	0.45 ± 0.01	0.40 ± 0.01	0.33 ± 0.01
Total N (g kg^{-1})	0.99 ± 0.06	0.85 ± 0.07	0.79 ± 0.08	0.73 ± 006	0.57 ± 0.07
Available nutrients					
P (mg kg^{-1})	12 ± 5.3	11.58 ± 5.7	11.29 ± 6.2	10.38 ± 6.4	9.18 ± 7.2
K (mg kg^{-1})	115 ± 21	133 ± 32	135 ± 24	143 ± 19	156 ± 17
NH_4-N (mg kg^{-1})	5.5 ± 0.91	5.3 ± 0.88	4.8 ± 0.92	4.5 ± 0.99	4.0 ± 0.82
NO_3-N (mg kg^{-1})	5.5 ± 0.09	5.2 ± 009	4.4 ± 0.08	3.2 ± 0.07	2.6 ± 0.43
Soluble cations (1:5 soil: water extract)					
Na^+ (mmol L)	0.41 ± 0.009	3.32 ± 0.12	9.61 ± 0.42	12.98 ± 0.22	15.54 ± 0.32
Ca^+(mmol L)	0.52 ± 0.009	0.41 ± 0.023	0.65 ± 0.028	0.78 ± 0.021	0.89 ± 0.009
Mg^+ (mmol L)	0.23 ± 0.009	0.26 ± 0.012	0.22 ± 0.019	0.76 ± 0.023	0.81 ± 0.021
$SAR_{1:5}$	0.6	5.7	14.6	14.8	16.9