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Responses of Soil Microbial Activity and Biomass to Salinity After Repeated Additions of Plant Residues

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ABSTRACT

Microbial adaptation to salinity can be achieved through synthesis of organic osmolytes, which requires high amounts of energy; however, a single addition of plant residues can only temporarily improve energy supply to soil microbes. Therefore, a laboratory incubation experiment was conducted to evaluate the responses of soil microbes to increasing salinity with repeated additions of plant residues using a loamy sand soil with an electrical conductivity in saturated paste extract (EC_e) of 0.6 dS m^{-1}. The soil was kept non-saline or salinized by adding different amounts of NaCl to achieve EC_e of 12.5, 25.0 and 50.0 dS m^{-1}. The non-saline soil and the saline soils were amended with finely ground pea residues at two rates equivalent to 3.9 and 7.8 g C kg^{-1} soil on days 0, 15 and 29. The soils receiving no residues were included as a control. Cumulative respiration per g C added over 2 weeks after each residue addition was always greater at 3.9 than 7.8 g C kg^{-1} soil and higher in the non-saline soil than in the saline soils. In the saline soils, the cumulative respiration per g C added was higher after the second and third additions than after the first addition except with 3.9 g C kg^{-1} at EC_e of 50 dS m^{-1}. Though with the same amount of C added (7.8 g C kg^{-1}), salinity reduced soil respiration to a lesser extent when 3.9 g C kg^{-1} was added twice compared to a single addition of 7.8 g C kg^{-1}. After the third residue addition, the microbial biomass C concentration was significantly lower in the soils with EC_e of 25 and 50 dS m^{-1} than in the non-saline soil at 3.9 g C kg^{-1}, but only in the soil with EC_e of 50 dS m^{-1} at 7.8 g C kg^{-1}. We concluded that repeated residue additions increased the adaptation of soil microbial community to salinity, which was likely due to high C availability providing microbes with the energy needed for synthesis of organic osmolytes.

Key Words: C availability, electrical conductivity, microbial biomass C, microbial community, respiration, saline soil

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INTRODUCTION

The area affected by salinity is increasing in many regions of the world, especially in arid and semi-arid regions, which is often induced by poor irrigation and drainage management (Lambers, 2003). Salt accumulation negatively influences physical, chemical and biological soil properties (Rengasamy, 2006b). Salinity reduces plant growth because the high osmotic potential of the soil solution inhibits water uptake by plants and the ion toxicity and ion imbalance restrict nutrient uptake (Rengasamy, 2010). Furthermore, salinity reduces microbial biomass and activity and decomposition of soil organic matter (Batra and Manna, 1997; Pathak and Rao, 1998; Rietz and Haynes, 2003; Muhammad *et al.*, 2006; Ghollarata and Raiesi, 2007; Egamberdieva *et al.*, 2010; Setia *et al.*, 2011a; Elmajdoub and Marschner, 2013) and alters the microbial community structure because microbial genotypes differ in their tolerance to low osmotic potential (Pankhurst *et al.*, 2001; Sardinha *et al.*, 2003; Chowdhury *et al.*, 2011b; Andronov *et al.*, 2012). Salinity decreases the ratio of fungi to bacteria (Pankhurst *et al.*, 2001), indicating that bacteria are more tolerant to salinity than fungi. Salinity-tolerant microbes counteract the high osmotic potential by accumulating organic osmolytes to reduce water loss from their cells (Oren, 2001; Beales, 2004). The synthesis of osmolytes requires high amounts of energy and may therefore reduce microbial growth (Oren, 1999; Hagemann, 2011).

The addition of organic materials such as farmyard manure, crop straw and green manure can reduce the negative effects of salinity on plants by increasing soil aggregate stability and water-holding capacity and decreasing soil bulk density, electrical conductivity (EC) and exchangeable sodium percentage (ESP) (Yadvinder-Singh *et al.*, 2005). Moreover, addition of organic matter to saline soils provides ene-

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rgy and nutrients for soil microorganisms (Tejada *et al.*, 2006) because soil microbial activity and biomass are often C-limited (De Nobili *et al.*, 2001; Demoling *et al.*, 2007). We showed in a previous study (Elmajdoub and Marschner, 2013) that the addition of glucose or cellulose, particularly the easily available glucose, reduces the negative effect of salinity on microbial activity because the increased energy supply provided by organic C addition enables microbes to synthesise osmolytes. Many studies have shown that in saline soils, a single addition of plant residues increases microbial activity and biomass temporarily, after which activity and biomass return to values similar to those in unamended soils (Wichern *et al.*, 2006; Elgharably and Marschner, 2011; Li *et al.*, 2012). This suggests that adaptation of microbes to salinity requires high amounts of easily available substrates which are depleted rapidly in the first few days after addition of organic materials. Decomposition of recalcitrant compounds such as cellulose, hemi-cellulose and lignin is slow and requires release of extracellular enzymes, an ability that is limited to a small number of microbial groups (de Boer *et al.*, 2005; Vargas-García *et al.*, 2007; Meidute *et al.*, 2008). Thus, a single addition of plant residues can only temporarily improve energy supply to the majority of soil microbes. In the field, plant residue supply is continuous, *e.g.*, through litter fall or root turnover. Duong *et al.* (2009) showed that when the same total residue amount was added, repeated residue additions of wheat straw increased C mineralisation compared to a single addition. However, little is known about the effect of repeated additions of residues on responses of microbes to salinity.

The aim of this study was to determine the responses of soil microbes to increasing salinity with repeated additions of plant residues. We hypothesise that high organic C availability will reduce the negative effect of salinity on microbial activity and soil respiration will therefore be less affected by salinity when i) residues are added repeatedly compared to the single addition and ii) the total amount of C added over several additions is the same as the amount of C added in a single addition.

MATERIALS AND METHODS

Soil sampling

A non-saline loamy sand soil under natural vegetation was collected from 0–20 cm depth in Monarto, South Australia (35°05′ S and 139°06′ E). This area has a dry Mediterranean climate, with an average temperature of 30.1 °C in summer and 15.9 °C in winter. The average annual rainfall is 352 mm. The soil was composed of 83% sand, 5% silt and 12% clay. With a pH of 7.5, the soil had an EC in a 1:5 soil-water extract ($EC_{1:5}$) of 0.05 dS m^{-1}, total organic C of 6.2 g kg^{-1}, total N of 0.1 g kg^{-1}, total P of 0.25 g kg^{-1}, bulk density of 1.57 g cm^{-3} and maximum water holding capacity (WHC) of 0.17 g g^{-1}.

Incubation experiment

The soil samples were air-dried and sieved to < 2 mm before the incubation experiment in laboratory. In South Australia, top soils often remain dry over summer, therefore air-drying is a realistic pre-treatment. The experiment was arranged in a completely randomised design with three replicates. The soil samples were adjusted to different $EC_{1:5}$ levels by adding different amounts of sodium chloride (NaCl). The salt was dissolved in reverse osmosis (RO) water and added to bring the water content to 75% of WHC. The soil receiving only RO water was used as a control. Then, the soils were mixed and measured to ensure the desired EC levels: $EC_{1:5}$ levels of 0.05 (control), 1, 2 and 4 dS m^{-1}. The $EC_{1:5}$ levels were converted to electrical conductivity in saturated paste extract (EC_e) levels of 0.6, 12.5, 25.0 and 50.0 dS m^{-1} (hereafter referred to as EC0.6 (control), EC12.5, EC25 and EC50, respectively), by using the following equation (Rengasamy, 2006a):

$$EC_e = (14.0 - 0.13 \times CLAY) \times EC_{1:5} \quad (1)$$

where CLAY is the percentage of clay particles in soil. These EC levels represented non-, low, moderate and high salinity with respect to soil respiration, respectively, based on previous studies (Elmajdoub and Marschner, 2013).

The soils with desired EC levels were pre-incubated at 75% of WHC at 25 °C for 18 d to reactivate and stabilise soil respiration. Soil respiration usually stabilises after rewetting of air-dried soil for 8–10 d (Butterly *et al.*, 2009). The longer pre-incubation than usual was to allow the microbes to adapt to the different EC levels. A preliminary experiment was carried out to determine the effect of water content on cumulative respiration. The water content was adjusted between 20% and 80% of WHC with RO water in soil amended with 1.5 g C kg^{-1} as glucose and respiration was measured over 10 d. Cumulative respiration was maximal at 40%–75% of WHC with no significant differences within this range (data not shown).

The pre-incubated soils were amended with finely ground pea (*Pisum sativum* L.) residues (particle size: