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Maize residue application reduces negative effects of soil salinity on the growth and reproduction of the earthworm *Aporrectodea trapezoides*, in a soil mesocosm experiment

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ABSTRACT

We studied the effects of maize residue application on some life-cycle parameters of the earthworm *Aporrectodea trapezoides* in saline agricultural soils with electrical conductivity (EC) ranging from 1.58 to 7.35 dS m^{-1}. This experiment was carried out under controlled laboratory conditions for 150 days. Results showed that soil salinity significantly affected the growth and reproduction of earthworms, decreasing survival, numbers and mean fresh weights of adults, juveniles and cocoons. Maize residue application gave a greater survival of earthworms at all salinity levels, but the differences were only significant at an EC of 7.35 dS m^{-1}, although the mean weight of adult earthworms was significantly increased by maize residue application at all salinity levels. At an EC of 1.58 dS m^{-1} and 3.35 dS m^{-1}, the application of maize residues gave significantly higher numbers of cocoons and juveniles, but in soils with 5.26 dS m^{-1} and 7.35 dS m^{-1} earthworms did not produce any cocoons over the experimental period, irrespective of maize residue application. These results indicated that maize residue application alleviated the negative effects of soil salinity on the growth and reproduction of *A. trapezoides* up to 3.35 dS m^{-1}, above which maize residues only increased the growth but not on the reproduction of earthworms.

1. Introduction

Saline soil is an important land resource for agriculture, but salinity is a major edaphic factor limiting agricultural production in many coastal areas (Lin et al., 2006). These regions usually have a shallow groundwater table with saline groundwater. In the west coast of the China's Bohai Bay, spring and autumn are two accumulation periods of soil salt because of low rainfall and high evaporation (Li et al., 2008). The soil salinization process probably affects the chemical and physical properties of soil, soil microbiological processes, plant growth and soil fauna (Tejada and Gonzalez, 2005; Wichern et al., 2006; Rietz and Haynes, 2003; Sumner et al., 1998; Zhang et al., 2010). Changes in environmental characteristics of soil could reduce the survivability of soil fauna in agroecosystems, especially earthworms (Ammer et al., 2006). Earthworms are involved in key soil processes such as soil organic matter decomposition, soil nutrient turnover, aggregate formation and soil pore water dynamics through their burrowing activities (Edwards et al., 1990; Blair et al., 1995; Schindler-Wessells et al., 1997; Brown and Doube, 2004) and act as so called "ecosystem engineers" as they modify the habitat in which they live (Lavelle et al., 1997). The importance of earthworms as soil engineers depends to a large extent on their population biomass and reproduction. Studies have been conducted into the use of crop residues as a potential large-scale feed for earthworm (Shipitalo et al., 1988; Cook and Linden, 1996).

It has been demonstrated that organic residues, mainly in the form of agricultural wastes, can be used to provide essential nutrients (such as N, P and K) to rebuild soil physico-chemical properties, and enhance soil microbial and faunal populations and activities (Hanay et al., 2004; Tao et al., 2009; Thomson and Hoffmann, 2007). According to a conservative estimation, around 590–730 million tones of crop residues are available in China every year, but most is usually burnt or remains unutilized (Gao et al., 2009; Xie et al., 2010). This huge quantity of agricultural waste can be converted into nutrient for sustainable land restoration practices. In salt-affected areas, the input of organic matter has become a common practice in the last decades (Raychev et al., 2001). The decomposition of organic matter added into soil could

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increase the concentrations of humic and fulvic acids that regulate the equilibrium between the adsorption of Na and the chelating of Ca and Mg by organic anions (Tejada et al., 2006). Amendments of organic matter improved soil structure, reduced exchangeable sodium percentage (ESP), increased microbial activities (Clark et al., 2007) and advanced plant growth. Liang et al. (2005) suggested that incorporation of organic manure can be regarded as a low-input effective agro-technological approach to minimizing salt constraints. Lakhdar et al. (2008) reported that application of organic matter could reduce the negative effects of salinity on plant growth. Additionally, the application of organic residues may influence the establishment of viable earthworm populations. By providing food sources and increasing the overall levels of soil organic matter, organic amendments usually can increase earthworm abundance (Bohlen et al., 1995).

Many previous studies mainly focused on the effects of organic matter on chemical, physical and microbial properties of salt-affected soils. However, the effects of organic residues on the growth and production of soil fauna in saline agricultural soils, especially endogeic earthworms, remain relatively unstudied. Our hypothesis, that we tested in a mesocosm experiment, was that organic residue application would increase growth of the earthworm *Aporrectodea trapezoides* and promote the production of cocoons and juveniles in salt-affected soils.

2. Materials and methods

2.1. Soil and substrates

Soil used in the experiment was collected from the top 20 cm of a long-term maize-wheat rotation field in the west coast of the China's Bohai Bay (38°22′E and 117°21′N). The soil was classified as a fluvisol and contained 42.8% sand, 30.1% silt and 27.1% clay. The soil had an organic matter content of 11.05 g kg^{-1}, total N content of 0.63 g kg^{-1}, pH (H_2O) 7.78 and an electrical conductivity of 1.58 dS m^{-1}. The soil was brought to the laboratory, sieved (5 mm), after carefully removing the surface organic materials and fine roots. Soil samples representing a range of EC values were prepared by spraying different volumes of underground saline water (18.5 dS m^{-1}), and again then air drying the soil. We prepared four soil samples with varying EC values (1.58 dS m^{-1}, 3.35 dS m^{-1}, 5.26 dS m^{-1} and 7.35 dS m^{-1}) and ion concentrations (Table 1). The soil sample with a relatively low EC of 1.58 dS m^{-1} was regarded as the control soil. After the soils were prepared, they were allowed to equilibrate for 2 d before being used in the experiments. Maize residues (C/N = 65.8) were sun-dried and milled to pass through a 2-mm diam. mesh before being mixed uniformly with soil as described below. There were eight treatments in a factorial design of soil EC (1.58 3.35 5.26 or 7.35 dS m^{-1}) and maize residues (with or without).

The endogeic earthworms *A. trapezoides* used in the experiments were collected from a vegetable field located in the west coast of the China's Bohai Bay by digging and hand-sorting. Only adult earthworms with body weights between 0.55 and 0.85 g and with fully developed clitella were selected for the experiment. This endogeic geophagous earthworm is a common species in the study area, feeding and living within the soil. Subsamples (2 kg) of each of the salinity levels were placed in four replicate containers without maize residues and another four replicate containers with maize residues (40 g). Six adult earthworms (total weight 4.5 ± 0.3 g) were added into each container. Earthworms were previously washed with distilled water, blotted dry and weighed. All containers were covered with perforated lids to limit water loss due to evaporation. The soil moisture content adjusted to 70% of maximum field capacity and the containers were randomly placed in an incubator with 12 h light, 12 h dark at 15 ± 1 °C for 150 days.

Table 1
Mean values (S.D) of soil electrical conductivity and ion concentrations in four experimental soils.

	S1	S2	S3	S4
Electrical conductivity (dS/m)	1.58 (0.09)	3.35 (0.13)	5.26 (0.13)	7.35 (0.10)
Na^+ (mg/L)	31.32 (2.63)	63.75 (10.59)	113.92 (1.36)	175.90 (3.65)
K^+ (mg/L)	5.84 (0.40)	10.24 (4.72)	7.97 (0.55)	11.47 (0.82)
Mg^{2+} (mg/L)	7.28 (0.70)	12.5 (1.56)	18.86 (0.15)	23.67 (0.60)
Ca^{2+} (mg/L)	24.45 (3.01)	30.98 (3.58)	42.05 (0.59)	51.50 (1.64)
Cl^- (mg/L)	39.51 (2.78)	122.08 (13.40)	254.92 (5.36)	377.08 (7.13)
NO_3^- (mg/L)	2.46 (0.21)	2.55 (0.28)	3.50 (0.21)	2.42 (0.07)
SO_4^{2-} (mg/L)	28.95 (1.38)	42.45 (3.28)	65.50 (1.10)	87.82 (6.98)

2.2. Sampling and analysis

Sampling was done at days 4, 14, 30, 60, 90 and 150 after earthworms were introduced into the soil. We had destructively sampled and rebuilt the soil containers each time. Measured parameters were earthworm numbers, growth, survival, cocoons and juveniles. Growth was determined by individually weighing surviving earthworm from each container, and comparing the mean weight with initial values to calculate weight change. Survival was assessed by stimulating the worm with a blunt probe and an earthworm was judged dead if no response could be observed. Earthworms not found during sampling were judged to be dead since earthworms tissue decomposed easily in soil. The cocoons, mainly concentrated in the bottom of container, were collected manually from the soil profile at each sampling time and then were returned into soil of the containers to observe hatch of cocoons. Cocoon number per worm was calculated by dividing the total number of cocoons by the number of surviving adult earthworms. Juveniles were discovered in some soils from days 90, and they were collected and counted.

2.3. Statistical analysis

A repeated measure analysis of variance (RM-ANOVA) was used to analyze the effects of application of maize residues and soil salinity on numbers and mean weight of earthworm at different sampling times. The same procedure was used to analyze the effects of application of maize residues and soil salinity on the number of cocoons at days 30, 60, 90, 150 and juveniles at days 90, 150. Differences between means were tested with the LSD test ($p < 0.05$). All statistical analyses were completed using SPSS 16.0 (SPSS Inc., Chicago, IL).

3. Results

Soil salinity significantly ($P < 0.05$) reduced earthworm numbers, which were lower in the soils with 7.35 dS m^{-1} compared to in the other treatments at days 30, 60, 90 and 150, with or without maize residue (Table 2; Fig. 1). Maize residue application also significantly affected earthworm numbers, depending on soil salinity levels. Soil with added maize residues contained significantly ($P < 0.05$) greater numbers of earthworms at 7.35 dS m^{-1} than in soil of the same salinity without maize residues (Table 2; Fig. 1). Mean survival rate of earthworms was more than 80% in the soils with a EC of up to 5.26 dS m^{-1}, with or without maize residues, but was significantly ($P < 0.05$) affected at an EC of 7.35 dS m^{-1} (Fig. 3). The application of maize residues gave a greater survival of earthworms compared to the soils without maize residues at all salinity levels, but the differences were only significant for the highest salinity level (Figs. 2–4).

There was a significantly ($P < 0.05$) lower mean weight of earthworms at an EC of 7.35 dS m^{-1} than that at the other salinity