The influence of land use practices on earthworm communities in saline agriculture soils of the west coast region of China's Bohai Bay

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ABSTRACT

The effects of land use practices on soil fauna, especially earthworms, are poorly known in coastal saline agricultural soils. Here we compare earthworm communities in six types of land use practice in the coastal region of China's Bohai Bay, namely uncultivated saline soil, two orchard (pear and winter jujube) lands, man-made forests (chinese ash), vegetable land and cropped land (maize). In addition, we recorded selected physicochemical properties of the soil. Soil organic matter content and total N were significantly higher under pear orchard and vegetable land than under the other land use practices, and their lowest values were observed from uncultivated saline soil. Vegetable land and pear orchard land showed a significantly higher abundance of earthworms than the other land use practices, whereas no earthworm was found in uncultivated saline soil. The sites under individual practices supported one to three earthworm species. *Aporrectodea trapezoides* species was present under four types of land use practice, and the biomass of this species accounted for more than 60% of the community. Vegetable land and pear orchard land supported richer earthworm community than the other land use practices, dominated by *Aporrectodea trapezoides* and *Drawida japonica.* These preliminary results indicated that land use practices have substantial effects on the abundance and composition of earthworm communities in saline soils.

Keywords: soil fauna; community structure; biological environment; salt-affected agricultural soils

The conversion of natural tropical ecosystems to agricultural ecosystems may accelerate the changes of the soil. This implies not only a change in soil chemical properties, but also a change in biodiversity (Hairiah et al. 2001, Wu et al. 2001). Adequate management of land use may favor environmental conditions required by certain groups of soil flora and fauna (Geissen et al. 2009). The studies of Emmerling (1995) showed that land use and soil organic matter content were the main factors affecting the distribution of soil macrofauna. Dlamini and Haynes (2004) also found agricultural land use impacted on the size, composition and diversity of earthworm communities in agricultural soils. In return, management of earthworm populations is becoming more important for sustaining soil productivity and fertility in agro-ecosystems (Whalen et al. 1998).

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However, the research on the effects of land use practices (forest, orchard, cropped land, etc.) on soil faunal communities is still lacking in saline agricultural soils, where land use practices may substantially affect physical, chemical and biological properties of the soils (Qiao et al. 2001). Changes in environmental characteristics of soil could affect the community of soil fauna in soils, 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, Wessells et al. 1997, Brown and Doube 2004) and act as so called 'ecosystem engineers' (Lavell et al. 1997). Moreover, the relationships between earthworm abundance and soil properties could be used as indicators of the performance of agricultural systems in terms of soil quality (Clapperton et al. 2004).

Two main research questions were examined in the present study: (1) did the abundance of earthworm communities vary among land use practices in saline agricultural soils of the west coastal region of China's Bohai Bay; (2) What land use practice optimizes the use of soil in driving the improvement of ecosystem environments in a region of saline agricultural soils?

MATERIAL AND METHODS

Sites and soils. The study area was located within the Zhongjie friendship farm (117°37'E, 38°25'N) of Hebei province in west coast of China's Bohai Bay. The area belongs to semi-humid continental monsoon climate zone with average annual temperature of 12.3°C. Average annual precipitation is 590.6 mm, of which most occurs from late June to September. However, precipitation is highly variable. Average mean annual evaporation is 2117.4 mm. Most sites have gone through several land uses and known history of fields was: > 8 years pear orchard (*Pyrus ussuriensis* Maxim), > 10 years winter jujube orchard (*Zizyphus jujube* Mill. cv. Dongzao), > 6 years chinese ash forest *(Fraxinus chinensis* Roxb), > 11 years vegetable land (*Brassica rapa* L. and *Allium fistulosum* L.), > 15 years cropped land (*Zea mays* L.). The uncultivated saline soil was used as a control. In cropped land, conventional farming was practiced by monoculture of maize (to a lesser extent of wheat), using mechanical tillage, removal of crop straw and application of inorganic fertilizer. In winter jujube land, fertilizer, pesticides and herbicides were applied each year, whereas in pear land maize straw was covered onto the soil surface (besides fertilizer application). In Chinese ash forest, weeding and pest management operation were timely performed in those first few years. In vegetable land, cabbage seeds and scallion were cultivated each year. Large amount of manure were applied as basal fertilizer for vegetative soil. The soils in the area are classified as salinization tidal soils, composed of clay (27.1%), silt (30.1%) and sand (42.8%).

Earthworm sampling and identification. A total of 18 fields (three replicates of each type of land practice) were sampled in October, 2010. Within each field area (approximately 0.2 ha), three plots (about 15 m^2 in area) were randomly chosen. At each plot, a 50 cm × 50 cm area was excavated to the depth of 30 cm and the soil block was then hand-sorted to collect earthworms. Additionally, formalin was added to the bottom of the sampling holes (Raw 1959) but no additional deep burrowing earthworms were was collected. The earthworms collected from each sampling point were counted in the field, placed in vials containing 70% ethanol and transferred to the laboratory for identification. All worms were washed clean of adhering soil, patted dry with a paper towel and weighed for total fresh biomass. Earthworm species were identified using the keys by Yin (1992).

Soil sampling and analysis. Adjacent to each earthworm sampling point, three soil cores of area of 2.5 cm^2 to depth of 30 cm were taken randomly using a steel core and pooled together as one composite sample. Soil samples were air-dried and ground. The soil analysis followed the 'Analysis of soil characteristics' (Lu 2000). Bulk density (BD) of each soil core was calculated as the total mass of oven dried soil divided by the core volume. Organic matter content was analyzed on ground soil by the Walkley and Black dichromate oxidation method (Blakemore et al. 1972). The total N content was determined using the Kjeldahl method. Soil pH was measured in a 1:5 soil:water (distilled water) slurry using a glass electrode. Available P was extracted with 0.5 mol/L $NaHCO_3$ by the Olsen method. Available K was extracted with 1 mol/L NH_4OAc and was determined in all pot soil samples. Soil electrical conductivity was extracted using a 1:5 soil:water suspension and were determined with conductivity meter.

Statistical analysis. An analysis of variance (ANOVA) was performed to test for significant differences between the study sites, when the normality assumption (Kolmogorov-Smirnov test) was met. Non-normal distribution of the data was first log-transformed and then was tested with an analysis of variance (ANOVA). The standard error of the mean for values for each land practice was calculated using the three replicated sampling fields, three points in each. All differences were assessed using one-way ANOVA. Differences between means were tested with the *LSD* test ($P < 0.05$). The relationships between the number and biomass of earthworms and specific soil parameters were expressed by linear correlation coefficient. All statistical analyses was done using the software package SPSS 16.0 (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

The measured physical/chemical properties of the soils are presented in Table 1. Both organic matter content and total N were significantly higher under pear orchard and vegetable land than the other land use practices, and their lowest values were observed on uncultivated saline soil. In vegetable land, chinese cabbage residues was return into soil annually and inputs of manure. Pear orchards are grassed-down so organic matter inputs occur mainly through turnover of grass root material and irregular inputs of maize straw. Qiao et al. (2001) found that vegetable land use practice showed a higher organic matter content than other land use practices, which was closely related to the inputs of fertilizer.

Land management practices applied to the saline soil are likely to have some positive effects on habitation of soil fauna (Emmerling and Paulsch 2001). The present study showed that the abundance of earthworms under vegetable land (> 340 individuals/m^2) and pear orchard land use practices (> 120 individuals/m^2) was significantly higher than those under the other land use practices (Figure 1), which may be due to the inputs of organic residues. Lowe and Butt (2002) found that organic matter management is important in the development of sustainable earthworm populations and their role in soil amelioration at restored sites. According to Sumner (1995), soils are generally classified as saline when they have an EC of 4 dS/m or more. Vegetable lands had a higher soil salinity concentrations considered to be 'unsafe' for many plant (Schoeneberger et al. 2002), but the soil salinity concentration had no effect on the population of earthworms. We speculated that higher organic matter content under vegetable land, which provided substrates or food resources for the soil organisms, probably reduces the negative effects of soil salinity on soil organisms (Pathak and Rao 1998, Wichern et al. 2006). The previous study of Tao et al. (2012) suggested that maize residue application alleviated the negative effects of soil salinity on the growth and

Table 1. Mean values (± standard error, n = 3) of soil physicochemical parameters in different types of land use

	Organic matter content	Total N	Available K	Available P	Soil electrical conductivity (dS/m)	pH	Bulk density (g/cm^3)	Soil water content (%)
	(g/kg)		(mg/kg)					
Uncultivated saline soil	10.75 ± 0.12^c	0.47 ± 0.02^c	195.00 ± 7.64^c	12.51 ± 0.54^b	20.64 ± 3.01^a	7.65 ± 0.05^a	1.35 ± 0.01^a	25.55 ± 0.50^b
Pear orchard	13.18 ± 0.47^b	0.94 ± 0.05^a	336.67 ± 54.87^b	13.46 ± 0.97^b	1.86 ± 0.29^c	7.68 ± 0.04^a	1.16 ± 0.03^c	26.31 ± 1.34^{ab}
Winter jujube	10.98 ± 0.03^c	0.55 ± 0.01^{bc}	226.67 ± 8.82^{bc}	13.99 ± 0.57^b	1.32 ± 0.25^c	7.81 ± 0.03^a	1.28 ± 0.02^{ab}	22.54 ± 1.25^c
Chinese ash forest	10.70 ± 0.14^c	0.48 ± 0.44^c	228.33 ± 24.55^{bc}	13.50 ± 0.61^b	1.48 ± 0.50^c	7.73 ± 0.06^a	1.37 ± 0.01^a	16.06 ± 0.50^d
Vegetable land	16.61 ± 0.52^a	0.92 ± 0.49^a	600 ± 70.24^a	18.85 ± 0.78^a	4.49 ± 1.17^b	7.84 ± 0.09^a	1.20 ± 0.05^{bc}	28.86 ± 0.87^a
Cropped field	11.05 ± 0.14^c	0.63 ± 0.47^b	203.33 ± 17.63^c	14.14 ± 0.81^b	2.43 ± 0.37^c	7.78 ± 0.06^a	1.20 ± 0.06^{bc}	22.06 ± 0.57^c

Different letters indicate significant ($P < 0.05$) differences for each parameter among different land uses (by *LSD* test)

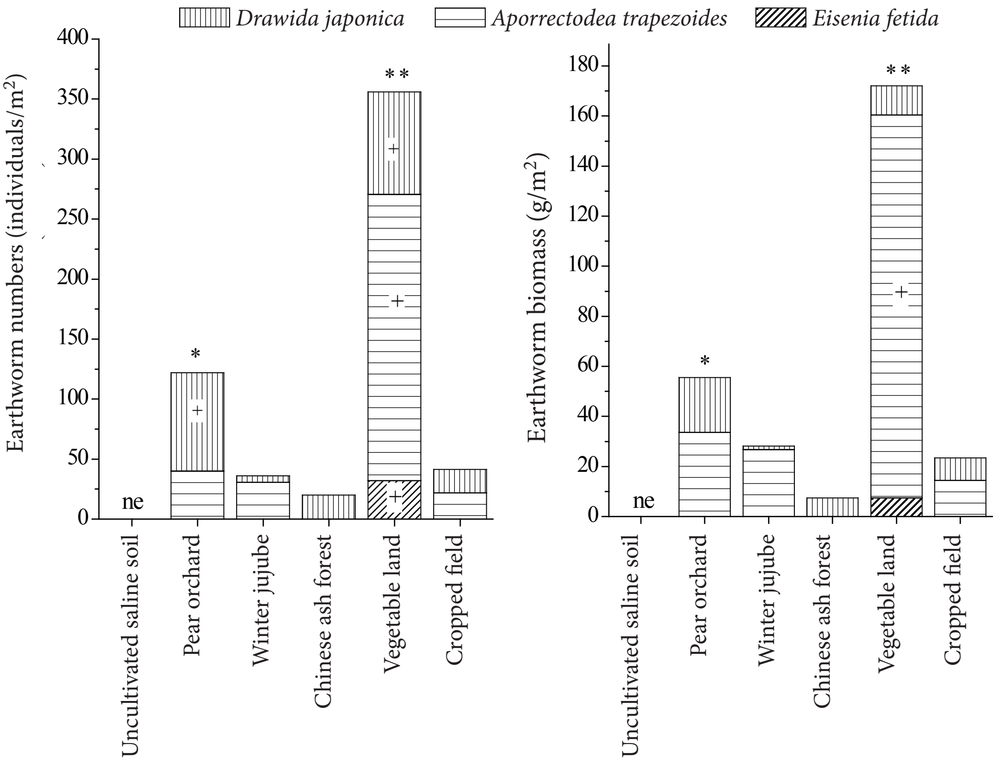

Figure 1. Mean earthworm numbers and biomass (n = 3) under different land uses. All numbers and biomass differences are respectively compared at $P < 0.05$ for total earthworm (*) or species (+); ne – no earthworms

reproduction of *A. trapezoides*. Additionally, under vegetable land and pear orchard land the farmers brought in organic manures or material from outside each year, which is the possible source of earthworms. The high abundance of earthworms under vegetable land and pear orchards land, in turn, would improve soil quality and enhance soil nutrients (Baker 2007, Eriksen-Hamel and Whalen 2008). However, under uncultivated saline soil, the higher soil salinity concentration or lower organic matter maybe limited production or invasion of earthworms from other lands.

Both cropped land and winter jujube land showed a low abundance of earthworms (Figure 1), which may be due to the types of land use practices. In cropped land, besides ordinary tillage, maize straw was removed from the field and burned annually. In winter jujube land, because of herbicide application soil surface is essentially bare apart from a thin layer of winter jujube leaves. These soil management practices adversely affected the population of soil fauna. But inorganic fertilizer application in both land uses, in order to increase their yields, could improve root growth of crop to keep a certain number of earthworms (Leroy et al. 2008). In two orchard land, pear land showed a significantly higher abundance of earthworms than winter jujube land, maybe because pear land is covered with organic residues and grass. In Chinese ash forest, there was a layer of ash leaves and inorganic fertilizer was not added into the soil. Earthworms are less abundant in Chinese ash forest (< 50 individuals/m^2) (Figure 1), which could be due to lack of inorganic fertilizer. Inorganic fertilizer can promote decomposition of organic litter and growth of plant that affect soil microorganisms and fauna in low-level nutrient soils (Edwards et al. 1995). The uncultivated saline soil floor is essentially bare. As a result, organic matter content and total N were lower under uncultivated saline soil than the other land use practices. Earthworms do not occur under uncultivated land. Earthworm numbers and biomass were positively correlated with soil organic matter content and total N, in contrast with soil bulk density which showed a negative correlation (Table 2). These results were consistent with the general view (Reeleder et al. 2006, Huerta et al. 2007, Ouellet et al. 2008).

In the present study, different land use practices were supported. Saline agricultural soils except for uncultivated land (Figure 1). Improved vegetable land and pear orchard land had a larger

Table 2. Linear correlation coefficients between measures of selected soil properties and earthworm total numbers and biomass

Measures of earthworms	Organic matter content	Total N	Available K	Available P	Soil electrical conductivity	pH	Bulk density	Soil water content
Total numbers	0.938**	0.943**	0.771	0.657	0.029	0.600	–0.841*	0.600
Total biomass	0.886*	0.847*	0.829*	0.600	–0.143	0.657	–0.754	0.657

*$P < 0.05$; **$P < 0.01$

earthworm community and was dominated by endogeic *Aporrectodea trapezoides* living in a mineral soil layer and feeding on mineral particles of soil (Bonkowski and Schaefer 1997). The second predominant species was *Drawida japonica*. The number of *Drawida japonica* was higher under pear orchard than winter jujube, which may be due to roots of weed under pear orchard. This species may be likely to live around roots of plant. *Eisenia fetida* is an epigeic species and used as composting worm, preferring to live near the surface of the soil. This earthworm specie was present only under vegetable land, which was due to large amount of manure application for growing vegetables. In summary, different land use practices affected earthworm community characteristics in saline soil of the west coast region of China's Bohai Bay. Both vegetable land and pear orchard land use practices maybe optimizers the use of soil in driving the improvement of ecosystem environments in saline soils of the west coast region of China's Bohai Bay.

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