Changes in soil nutrients and carbon properties in relation to grassland salinization

Xuemao Zhao¹, Yao Zhong¹ and Chengchen Pan²*¹

¹ College of Geographic and Environmental Science, Northwest Normal University, Lanzhou, Gansu, China
² Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, CAS, Lanzhou, Gansu, China
*Corresponding author’s email: panchengchen@163.com

Abstract. Soil salinization is one of the most serious problems in arid and semiarid zones. In this study, we estimated the relationship between aboveground plant communities and belowground soil nutrients and soil carbon storage and salinity in grasslands in the middle reaches of Hexi Corridor, China. Four types of salinized grasslands including lightly, moderately, heavily, and severely salinized grasslands were selected. Aboveground biomass, plant species richness and diversity of plant community decreased significantly with salinity increasing. Salinization resulted in significantly increase in soil available phosphorus, and decrease in soil organic carbon, total nitrogen, available nitrogen, total potassium. No significant difference in total phosphorus was observed. Our results indicate that ecosystem functions such as aboveground biomass, vegetation cover, and some nutrients accumulation in soils are disturbed by salinity. However, we still appeal to protect the naturally salinized grasslands for not only their conservation of endemic and rare plants and animals.

1. Introduction
Grassland salinization, one of the most serious types of grassland degradation, occurs mainly in arid and semiarid regions, and has become a major concern throughout the world [1,2]. In China, about 29.3 million ha grasslands are affected by soil salinization. Salinization alters not only vegetation community [3], but also soil properties and the soil carbon-sink function [4,5]. However, soil physical and chemical properties vary with experimental location, salinity/sodicity degree, and salinity/sodicity distribution pattern under field conditions [6]. Many studies have reported inconclusive, even contradictory results [7,8,9]. Therefore, a better knowledge on soil nutrients and organic carbon in salt-affected soils in China is needed. Soil nutrients and organic carbon availability are critical for plant growth and development [10,11]. Therefore, understanding distribution of soil nutrients and organic carbon in relation to salinization is important to estimate rates of ecosystem processes, understand how salinization affects ecosystem [12] and predict soil nutrients change under climate change [13].

The experiment was conducted on the naturally salt-affected grasslands in the middle reaches of Hexi Corridor, China. In this region, salt-affected grasslands are estimated to 1.4 million ha, accounting for 79% of the total salt-affected soils [14]. Relatively little information is available on soil properties and the soil carbon-sink function in relation to salinization in this region. Here, we analyzed...
effects of grassland salinization on plant community properties, and soil nutrient properties and soil carbon storage.

2. Material and methods

2.1. Study area
The study area (39°11′07″—39°12′15″N and 100°06′4″E), the middle reaches of Hexi Corridor region in Gansu province of northwest China, is located at the southern edge of the alluvial fans of Heihe River with Qilian Mountain as its only source of water available. The average elevation is about 1400m above sea level. The climate in this region is characterized with temperate continental arid monsoon climate, dry and hot in the summer and cold in the winter. The annual mean precipitation is 121.5 mm, of this 61% is received in summer and autumn, while the annual mean evaporation is over 2,338 mm. Annual mean temperature is 7.1ºC, while the absolute maximum may reach 38ºC and minimum –28ºC. The soils in this region are identified as salinized meadow soils and salinity soils which are mainly sulphate salt, and have an alkaline pH [9].

2.2. Experimental design
A space-for-time substitution approach was used in this work [15]. According to the classification of salinization types and degrees, four types of salinized grasslands were selected including lightly (200–400 mS/m), moderately (400–800 mS/m), heavily (800–1600 mS/m), and severely (>1600 mS/m) salinized grasslands. For each treatment three plots (10 m × 10 m) were established for measurements.

2.3. Vegetation sampling
Five quadrates (2 m × 2 m) were randomly placed to evaluate Achnetherum splendens, Salsola paserina and Nitraria tangutorum in the heavily and severely salinized grasslands, and smaller quadrates (0.5 m × 0.5 m) were used for herbaceous vegetation in each plot in August 2011. All lower and higher plant species were identified to the species level, counted and plant height was determined. Aboveground standing biomass was clipped in each quadrate, the plant material was dried at 65ºC for 72 h and the dry weight determined. Shannon-Wiener diversity index (H) and Evenness index (E) were calculated.

2.4. Soil sampling
In August 2011, five soil samples collected at the depths of 0–10 cm, 10–20 cm and 20–30 cm within each plot using a bucket auger were mixed and taken to the laboratory. Soil bulk density was estimated at each plot using a soil corer (stainless steel cylinder with a volume of 100 cm³) at three depths (0-10 cm, 10-20 cm and 20-30 cm), with five replicates.

In the laboratory, roots and incorporated litter in each soil sample were removed, air-dried, and divided into two parts. One part was sieved to 2 mm used for determining electrical conductivity (EC). The second part was further sieved to 0.25 mm and used for determining average organic carbon and nutrient concentrations such as soil total nitrogen, total phosphorus, available nitrogen, available phosphorus, and available potassium [16].

The amount of organic carbon in each soil was calculated by the following equation [17]:

\[ \text{Soil organic carbon concentration} = \frac{\text{organic matter concentration} \times 0.58}{1} \]

\[ \text{Soil organic carbon storage} = \text{(soil area)} \times \text{(soil depth)} \times \left( \frac{\text{soil average bulk density}}{300} \right) \times \left( \text{average organic carbon concentration} \right) \]

2.5. Data analysis
Two-way ANOVA analyses were used to assess the effects of salinization, soil depth and their interaction on soil properties and soil organic carbon. One-way ANOVA analyses were used to assess the effect of salinization on vegetation community properties and soil carbon storage. All analyses were conducted in SPSS 16.0.
3. Results and discussion

Salinization significantly decreased aboveground biomass, species richness and diversity for salinized grassland, while species evenness index did not exhibit the similar pattern (Figure 1). As for soil nutrient properties in the process of grassland salinization, there were significant effects of salinized grassland type, soil depth and their interaction on soil EC, organic carbon, total nitrogen, available nitrogen and available potassium ($P < 0.05$). However, neither salinized grassland type nor soil depth or their interaction affected soil total phosphorus ($P > 0.05$). Soil available phosphorus and total potassium were affected by salinized grassland type ($P < 0.05$), but not by soil depth or their interaction ($P > 0.05$).

Figure 1. Effect of salinization on aboveground biomass (A), species richness index (B), Shannon-Wiener diversity index (C) and Evenness index (D) of grassland community. Values ($\pm$ SE) are means of all quadrates for lightly salinized grassland (L), moderately salinized grassland (M), heavily salinized grassland (H) and severely salinized grassland (S).

Grasslands were equipped with a higher soil EC, available phosphorus and lower soil organic matter, total nitrogen throughout different soil depths with salinity increasing (Figure 2). Most salinized soils are adequately supplied with phosphorus, even more readily available to plants than in comparable non-sodic soils [18]. For soil total phosphorus, no significant differences were observed throughout the profile among the four salinized grassland types (Figure 2). Soil total phosphorus showed no significant change with salinity increasing, while soil available phosphorus increased significantly. There might be two possible reasons for the increase of available phosphorus in our study. First, a high concentration of Na$^+$ ions results in the formation of soluble Na$_3$PO$_4$ [19]. In our study, concentration of Na$^+$ ions increased significantly with salinity increasing (unpublished data). Then more Na$_3$PO$_4$ formed with salinization development. Second, phosphorus is an essential element
for all plants. The inorganic phosphorus forms could be directly taken up by plants. For soil total potassium, no significant differences were found throughout the soil profile in the remaining three salinized grassland types ($P > 0.05$) when the light salinized grassland was excluded (Figure 2). In the lightly, moderately and heavily salinized grasslands, soil available potassium decreased throughout different soil depths, but opposite result was shown in the severely salinized grassland (Figure 2).

There was a significant effect of salinized grassland type, soil depth and their interaction on soil organic carbon (Table 1). Soil organic carbon showed a significant decrease throughout the soil profile with salinity increasing (Figure 3). Compared to the lightly salinized grassland, soil organic carbon decreased by 81.6%, from 22.3 to 4.1 g kg$^{-1}$ soil, 73.7%, from 11.8 to 3.1 g kg$^{-1}$ soil, and 66.3%, from 9.8 to 3.3 g kg$^{-1}$ soil at 0-10 cm, 10-20 cm and 20-30 cm in the severely salinized grassland, respectively.

For soil organic carbon storage, the similar pattern with soil organic carbon was showed. The amount of soil organic carbon decreased significantly with salinity increasing (Figure 3). Compared to the lightly salinized grassland, soil organic carbon storage decreased by 72.3%, from 4.7 to 1.3 kg m$^{-2}$ soil in the severely salinized grassland.

Correlation analysis among soil nutrients and vegetation properties in the process of grassland salinization are shown in Table 1. In the grassland salinization process, there were significantly positive correlations among soil organic carbon storage, soil organic C, plant diversity index, richness index and aboveground biomass.

Plant productivity is an important measure of ecosystem function [20]. Net primary productivity varies with plant community composition, disturbance, topography, salinity content, pH, and the interaction of these factors. Vegetation properties affect ecosystem processes such as litter production and turnover [21], resulting in different carbon content in soils [22,23]. The soil carbon storage decreased substantially with grassland degradation [24]. The data of our study are consistent with this finding. In our study, soil carbon storage was significantly positively related to species richness and diversity index (Table 1). These results further suggested that soil carbon storage was closely related to vegetation properties in salinized grassland community. As the soil carbon and nitrogen cycle are tightly coupled [25], a change in one has a direct influence on the other, so patterns were similar between soil carbon and nitrogen contents.

![Figure 3. Changes (mean ± SE) in soil organic carbon (a) under three soil depths for four types of salinized grasslands and soil carbon storage (b) over the depth of 0-30 cm in four types of salinized grasslands.](image)

Different letters indicate significant differences at $P < 0.05$ in soil carbon storage among four types of salinized grasslands.

| Pearson’s correlation | EC   | Soil carbon | Soil organic | Richness | Diversity |
|----------------------|------|-------------|--------------|----------|-----------|

Table 1. Pearson’s correlation coefficients (R) among soil carbon storage over the depth of 0-30 cm, soil organic carbon, diversity index, richness index and aboveground biomass of four types of salinized grasslands.
coefficients (R)    storage      carbon     index     index

Soil carbon storage -0.79**
Soil organic carbon -0.76** 0.99**
Richness index -0.85** 0.93** 0.93**
Diversity index -0.68* 0.84** 0.81** 0.89**
Aboveground biomass -0.95** 0.72** 0.70** 0.82** 0.61*

4. Conclusions
Our results showed that some aspects of ecosystem functions such as plant biomass and some soil nutrients were disturbed by salinization. At present, there is a strong need for reclamation, improvement and utilization of salt-affected soils to meet the demands of economic and society development. However, the naturally saline habitats should be used in a sustainable way and/or protected, as they are vital for the conservation of many endemic and rare plant species and animals [26].

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