Ecological Indicators 88 (2018) 79–87

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Short-term land use conversions influence the profile distribution of soil salinity and sodicity in northeastern China

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ARTICLE INFO

Keywords:
Revegetation
Solonetz
Sodium adsorption ratio
EC
Soil salinity
Songnen grassland

ABSTRACT

Soil salinity and sodicity are important factors leading to soil degradation. Understanding the changes in soil salinity and sodicity is important to maintain soil quality and health and for sustainable land use. The main objective of this study was to investigate the short-term influences of land uses on soil salinity and sodicity in northeastern China. The eight dominant soil soluble ions (sodium, potassium, calcium, magnesium, carbonate, bicarbonate, chloride and sulfate), pH, electrical conductivity (EC), total soluble salt content and sodium adsorption ratio (SAR) were determined at 0–50 cm depth under five land uses consisting of corn (*Zea mays* L.) cropland (Corn), alfalfa (*Medicago sativa* L.) forage land (Alfalfa), *Leymus chinensis* (Trin.) Tzvelev grassland (AG), *Leymus chinensis* (Trin.) Tzvelev grassland for mowing (AG + M) and restored grassland (RG). The results showed that sodium was the predominant cation in Songnen grassland, while the contents of carbonate, bicarbonate, chloride and sulfate had slight differences in the 0–50 cm depth. Compared with soil salinity, soil sodicity was a more serious problem due to the higher soil pH and SAR. EC and SAR were more sensitive to land use conversions due to the higher discrimination ability and value ranges by different land use treatments. Under AG + M, AG and RG treatment, soil EC (20.59%, 23.03% and 19.61%, respectively) and SAR (42.46%, 39.66% and 37.62%, respectively) were lower in the 0–10 cm depth, while soil EC (36.03%, 25.75% and 17.40%, respectively) and SAR (30.86%, 20.18% and 23.09%, respectively) in the 10–50 cm depth were higher than those under Corn. Soil EC and SAR under Alfalfa in the 0–50 cm depth were 4.69% and 1.97% lower than that under Corn, demonstrating that alfalfa planting was better than other land uses to improve soil salinity and sodicity in northeastern China. These results suggested that soil sodicity was a very serious problem in the Songnen grassland, and soil salinity and sodicity can be expected to gradually decrease with the conversion of cropland to grasslands in semi-arid agroecosystems.

1. Introduction

Soil salinity and sodicity, the main reasons for soil degradation in arid and semiarid regions are escalating problems worldwide (Mahmoodabadi et al., 2013; Gorji et al., 2017); they adversely affect the physical (Crescimanno et al., 1995; Rasouli et al., 2013), chemical (David and Dimitrios, 2002; Ferreras et al., 2006) and biological (Yuan et al., 2007) properties of soils and severely restrict the sustainable development of local agriculture (Bezborodov et al., 2010a,b; Singh, 2015). Globally, salt-affected soils reach approximately 1 billion hectares, which represent approximately 7% of the extent of the Earth's continents or 20% of the world's irrigated lands (Metternicht and Zinck, 2003; Qadir et al., 2006). However, the distribution and types of salt-affected soils in different regions and countries are significantly different due to the diverse climates, natural environments and soil formation processes. Recent trends and future projections suggest that with the increasing demands for food and fiber from a rapidly growing population and the reductions in soil resources caused by soil degradation, the sustainable use of salt-affected soils will gain more and more attention (Qadir et al., 2006; Bennett et al., 2009; Herrero and Castaneda, 2015).

As an extremely sensitive and fragile soil resource, salt-affected soils can be more easily influenced by land management practices than other soil types. Therefore, reasonable and effective management practices should be taken to prevent or improve soil salinity and sodicity during the utilization of salt-affected soils (Bennett et al., 2009). With intensive studies on the causes and processes of soil salinization and alkalization, several different physical, chemical and biological approaches, including the use of amendments, tillage, crop diversification, irrigation, mulching and revegetation have been used to ameliorate salt-affected

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https://doi.org/10.1016/j.ecolind.2018.01.017
Received 14 September 2017; Received in revised form 6 January 2018; Accepted 9 January 2018

soils for sustainable agriculture (Barrett-Lennard, 2002). Of these, revegetation has been used commonly due to its low cost and efficiency in ameliorating salt-affected soils (Barrett-Lennard, 2002; Jiang et al., 2010; Devkota et al., 2015). Different vegetations have diverse influences on changing soil moisture content and redistributing salts through plant-soil feed-backs due to their different abilities of using soil water and nutrients (Nosetto et al., 2008; He et al., 2014; Korkanç and Korkanç, 2016). Therefore, selecting suitable vegetation to restore degraded soils caused by soil salinization and alkalization is the essential prerequisite of sustainable agriculture in a specific region.

Songnen grassland, one of the largest salt-affected soil regions in China, is located in the eastern part of the northern agro-pastoral zone in China. In recent decades, the Songnen grassland has suffered from substantial land salinization and alkalization with the area of saline-alkali land increasing from 4.01×10^5 ha in 1954 to 10.97×10^5 ha in 2005 because of the double influences of human activity and climate change (Yang et al., 2010). The increases in soil alkalinity and sodicity have adversely influenced the soil properties in terms of crusting, low permeability and infiltration rates (Qadir and Oster, 2004; Rasouli et al., 2013), and thus, these increases have harmfully affected the sustainable development of regional agriculture and animal husbandry. Furthermore, the steep rise of corn production in China from 1.06×10^8 tons in 2003 to 2.25×10^8 tons in 2016 resulted in yield oversupply, leading to a notable reduction in corn price and planting benefit (Chen et al., 2016; Yu et al., 2017). To ameliorate the problem of degraded soils and improve the benefits of planting, the Chinese government implemented a range of policies and subsidies to guide framers in planting grass or forage in areas with poor environmental conditions, thereby expanding the regional animal husbandry and increasing the farmer's income. Approximately 5.33×10^4 ha of corn cropland was converted to forage or grass lands in Jilin Province in 2016 (Zhang, 2016). However, little is known about the effects of conversion of cropland to grasslands or forage land on the changes of soil salinity and sodicity in the Songnen grassland.

Thus, the main objectives of this research were to (1) investigate the changes of soil dominant soluble ions, soil pH, electrical conductivity (EC), total soluble salt content and sodium adsorption ratio under different land uses in the Songnen grassland, and (2) reveal the relationships between soil salinity and sodicity. We hypothesized that short-term revegetation could lead to decreases in soil salinity and sodicity and therefore improve soil quality in northeastern China.

2. Materials and methods

2.1. Study area

The study was conducted at the Changling Ecological Research Station for Grassland Farming (44°33′N, 123°31′E, 145 m a.s.l). The station is located in the south of the Songnen Grassland (Fig. 1). The area is characterized by a temperate, semiarid continental monsoon climate with annual average air temperature and precipitation of 5.9 °C and 427 mm from 1980 to 2013; approximately 70–80% of total precipitation occurs between June and September. The pan evaporation is approximately 1600 mm, and the frost-free period is approximately 140 days. The soils of the study area are alkali-saline, and are classified as Solonetz in the World Reference Base for Soil Resources (IUSS Working Group, 2015). The soils contain high contents of free sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3), and the pH of the soils range between 8.0 and 11.0. The dominant native species include *Leymus chinensis* (Trin.) Tzvelev, *Chloris virgata* Swartz, *Puccinellia tenuiflora* (Griseb.) Scribn and *Elymus dahuricus* Turcz. The vegetation coverage measures 50–90%, with 100–360 $g\,m^{-2}$ of aboveground biomass in the peak season (Yu et al., 2014).

2.2. Experimental design and soil sampling

The experiment was established in early May 2011 at a cropland and run for five years until soil sampling. Because of prior continuous plowing, soil conditions in the cropland before this experiment were homogeneous. Five land use treatments were designed in a completed block design with four replications. The five treatments were corn (*Zea mays* L.) cropland (Corn), alfalfa (*Medicago sativa* L.) forage land (Alfalfa), artificial grassland of *Leymus chinensis* (Trin.) Tzvelev (AG), artificial grassland of *Leymus chinensis* (Trin.) Tzvelev for mowing (AG + M) and restored grassland (RG). The block size was approximately 60 m × 50 m whereas the plot size was 12 m × 50 m for Corn and Alfalfa treatments and 6 m × 50 m for the AG and RG treatments. There was a 2-m buffer between the blocks and a 1 m buffer between the plots. Detailed descriptions of the five land use treatments are shown in Table 1.

Soil samples were collected in early September 2015 to a depth of 50 cm at five intervals of 0–10, 10–20, 20–30, 30–40, and 40–50 cm with a 4-cm diameter soil core sampler after removing the aboveground biomass and litter. A sample for each depth was composited by mixing sub-samples from five randomly selected locations (0.5 m × 0.5 m) at least 6 m apart from one another and at a 1 m distance from the plot boundary within each plot. One sub-sample was carried to the lab in a timely manner for the determination of soil moisture content. Another sub-sample was air-dried, separated from the root materials and other visible debris, and passed through a 2-mm sieve for other soil analysis.

2.3. Soil analysis

Soil chemical properties were determined by standard procedures

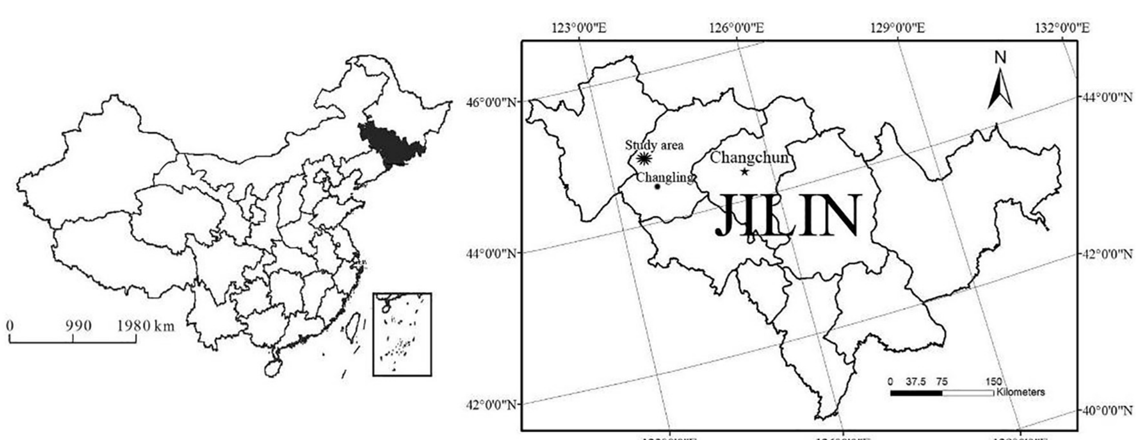

Fig. 1. The location map of the study area.