Clean – Soil, Air, Water 2010, 38 (11), 1010–1016

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Research Article

Biogeochemical Characterizations and Reclamation Strategies of Saline Sodic Soil in Northeastern China

Soil salinity and sodicity is considered one of the most import impediments to agricultural development in Northeast China. The contents of TP and TK decrease with soil depth and high coefficients of variation were found in TOC, AN, and AP. Mean EC in the 0–50 cm soil layers ranged from 0.61 to 0.89 $dS\,m^{-1}$ and the average soluble ion concentrations in the topsoil (0–10 cm) were approximately 11.38 $mmol\,L^{-1}$ for Na^+, 1.21 $mmol\,L^{-1}$ for Ca^{2+}, and 0.40 $mmol\,L^{-1}$ for Mg^{2+}. High SAR existed in the layers 10–50 cm, indicating the studied soil was bearing low salinity in the top layer and high sodic layer in the subsurface. The soil presented strong alkali reactions all through the profile with pH over 9.5. To improve and utilize saline sodic soil rationally, several strategies were put forward based on long-term field studies and demonstration works. The results implied that ameliorating with sand, applying farm yard manure, regenerating salt tolerant grasses and leaching with groundwater, and growing rice were effective measures for improving physical and chemical qualities of saline sodic soil.

Keywords: Biogeochemical characterization; Northeastern China; Nutrients; Reclamation strategies; Saline sodic soil

Received: July 9, 2010; *revised:* July 23, 2010; *accepted:* July 27, 2010

DOI: 10.1002/clen.201000276

1 Introduction

Saline soils cover about 380–995 Mha of the Earth's land surface [1, 2] and of these, 62% are saline-sodic or sodic soils. Soil salinity and sodicity is becoming more and more serious due to climate drying and human activities including overgrazing. Saline-sodic soil shows structural problems created by certain physical processes and specific conditions [3, 4]. Such problems may affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff, and erosion, as well as tillage and sowing operations in the saline sodic soils [5]. Accumulation of excess sodium (Na^+) in the soil causes the changes in soil exchangeable and solution ions and soil pH, destabilization of soil structure, deterioration of soil hydraulic properties, increases susceptibility to crusting and imbalances of plant-available nutrients in the soils [3, 6]. Owing to hydrolyzation of salts, plants growing on the soil suffer not only from sodium toxicity, but also from high pH stress caused by Na_2CO_3 and $NaHCO_3$. Thus agricultural productivities in most of arid and semiarid regions in the world are threatened by the occurrence of salts.

Reclamation of sodic soil requires removal of part or most of the exchangeable sodium, improvement of the soil physical structure, and lowering of pH value. In earlier studies, several scientists reported that it was possible to improve the structure of sodic soil using synthetic soil conditioners [7, 8]. Soil amendments, such as gypsum or calcium chloride, were commonly used as a supply of soluble calcium for the replacement of exchangeable sodium [9–15]. Other substances like sulphuric acid, sulphur, coal fly ash, and by-product from flue gas desulfurization (coal combustion coal products) that indirectly (chemically or biologically) made the relatively insoluble indigenous calcium carbonate found in sodic soils available for replacement of sodium and improvement of soil physical structure can be used [16–23]. The exchange reaction between gypsum and soil's exchangeable Na^+ depended on the contact of gypsum with soil particles and rate of removal of Na^+ from the soil solution. In most cases, fine gypsum was used because they dissolve more rapidly in water [12, 24]. For best results, after gypsum application, soluble Na^+ should be leached out of the root zone using good quality water so that the reaction proceeds in the forward direction [14]. However, many of effects of gypsum were limited to shallow depth and shortage of good quality water in most of arid and semi-arid regions. The biological methods are important ways for utilization or vegetative bioremediation of sodic soil now. Plants improved not only water flow in soils, also caused changes in the chemical properties of soils. In previous studies, it has been shown that plants can decrease soil pH [25, 26] and exchangeable sodium

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Abbreviations: **AK**, available potassium; **AN**, available nitrogen; **AP**, available phosphorus; **EC**, electrical conductivity; **ESP**, exchangeable sodium percentage; **FYM**, farm yard manure; **RAS**, Ratio of Alkali Spots; **RSC**, residue sodium carbonate; **SAR**, sodium absorption ratio; **TK**, total potassium; **TN**, total nitrogen; **TOC**, total organic carbon; **TP**, total phosphorus.

percentage (ESP) [25–28], increase soil organic matter, nutrients [29], and soil conductivity [9, 26]. Many studies have indicated improvements in soil physical and chemical properties by growing salt-tolerant species [9, 11, 25–27, 30, 31]. Some research works revealed the good results of sodic soil reclamation using bioremediation combined gypsum [11, 32–34]. Currently, limited studies have been performed on the combined benefits of crops and gypsum in reclamation of saline sodic soils.

In Songnen Plain, Northeastern China, there are approx. 3.73 Mha of saline sodic land with increasing rate of salinization and sodification at 0.6% per year in recent 50 years. Of these, 1.43 Mha is distributed in the west of Jilin Province [35]. With the increasing need for food security, saline sodic land in this region is of great concerns for both academic communities and local and central governments. A few amelioration experiments for saline-sodic soils in the Northeast China were carried out using leaching method with groundwater [36, 37]. However, biogeochemical characteristics of the saline sodic soil are not well investigated. This study focuses on (a) the biogeochemical characterization and (b) reclamation strategies for this exceptional ecosystem in the saline sodic soil of the western part of the Songnen plain, Northeastern China.

2 Materials and methods

2.1 Study area description

The study area is located in the west of Jilin Province (N40°52′–46°18′, E121°38′–131°19′), Northeastern China (Fig. 1). On the basis of satellite image interpretations and field surveys, saline sodic soils distributed in the west of Jilin Province covered about 28% of the province's total area [35] and more than 1/3 of the areas were degraded according to ratio of alkali spots (RAS; Fig. 1). The climate of this area is semi-arid and arid. Based on 30-year (1971–2000) monitoring data, mean annual rainfall in this area is 350–450 mm, of which 70–80% fall in July to September. Mean annual evaporation (1600–1800 mm) exceeds 4–5 times mean annual precipitation.

The study site is located at Da'an Experimental Station of Alkaline Sodic Soil, Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences, at approximately N45°35′58″–N45°36′28″, E123°50′27″–123°51′31″ (Fig. 1). The station is in Baicheng City, where the soil salinity and sodicity is heaviest in west of Jilin Province, about 74.1% of total saline sodic land is at severe graded. The topography is flat and the relative height is less than 35 m in the study area. The soil is a typical saline-sodic soil with the characters of salt and alkali accumulation in the surface soil. The main salts composition in soil solution includes Na_2CO_3 and $NaHCO_3$ with electrical conductivity (EC) of topsoil 0.1–2 dS m^{-1}, ESP 30–70%, and pH over 9. The soil is slowly permeable to fresh water because of large fraction of montmorillinite clay and sodium with infiltration rate about 12.1 mm h^{-1} [36]. The predominant land use types are farmland, pasture, and wetland with alkali lakes in this area.

2.2 Sampling and analysis

The 0–50 cm (0–10 cm, 10–30 cm, and 30–50 cm) soil samples were collected from degraded grass land in and around Da'an Sodic Land Experimental Station in spring 2005. Air dried soil samples were ground and sieved (<2.0 mm) for nutrient analysis. The content of total nitrogen (TN) and total phosphorus (TP) in soil samples were analyzed colorimetrically on a continuous-flow analyzer (Skalar San^{++}, Skalar, Breda, Netherlands). The total potassium (TK) was measured using the dry ash method. Total organic carbon (TOC) was determined by Total Organic Carbon Analyzer Model TOC-V_{CPH} (Shimadzu, Japan). Soil available nitrogen (AN), available potassium (AK), and available phosphorus (AP) were determined after extraction with potassium chloride, ammonium acetate at pH 7.0, and sodium bicarbonate, respectively. Soil pH and EC (soil/water = 1:5) were measured by pH B-4 portable pH meter (Shanghai Science Instrument Factory of Radium Magnetism, China) and DDS-307 conductivity meter (Shanghai Precision Scientific Instrument, China), respectively. Ca^{2+}, Mg^{2+}, and Na^{+} movement with $NH_4OAc/HOAc$ at pH 7.0 were measured by Perkin Elmer 2280 atomic absorption spectrophotometer.

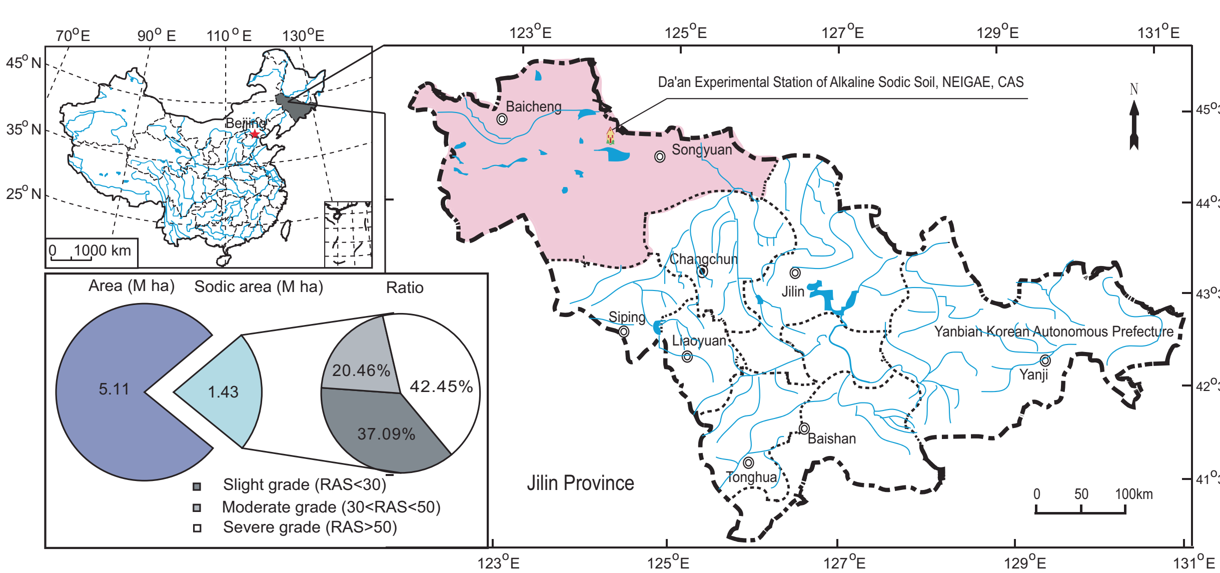

Figure 1. Distribution and area of saline sodic soil in Western Jilin Province, Northeastern China.

Sodium absorption ratio (SAR) in $(mmol_c\,L^{-1})^{1/2}$, alkalinity, and residue sodium carbonate (RSC) in $mmol\,L^{-1}$ were derived as follows: $SAR = Na^+/(Ca^{2+} + Mg^{2+})^{1/2}$; $Alkalinity = (CO_3{}^{2-} + HCO_3{}^-)$; $RSC = (CO_3{}^{2-} + HCO_3{}^-) - (Ca^{2+} + Mg^{2+})$.

3 Results and discussion

3.1 Nutrients in the saline sodic soil

Nutrient contents in 0–10 cm soil depth layer are 1.80–10.90 $g\,kg^{-1}$ for TOC, 0.40–0.97 $g\,kg^{-1}$ for TN, 0.16–0.39 $g\,kg^{-1}$ for TP, and 18.00–24.50 $g\,kg^{-1}$ for TK (Tab. 1). The means of AN, AP, and AK contents in this layer are about 43.40, 14.79, and 273.20 $mg\,kg^{-1}$, respectively. The contents of TP and TK decrease with soil depth. However, other nutrients varied both vertically and spatially. High coefficients of variation were found in TOC, AN, and AP. In soil layers below 30 cm, TOC, TN, TP, and TK mean contents were down to 4.18, 0.62, 0.21, and 19.75 $g\,kg^{-1}$, respectively. Compared with black soil which distributed in middle of Jilin Province where was main maize production area in China, the TOC, TN, and TP in the top layer of saline sodic soil were about 4–6 times lower than those in black soil, and available N, P, and K were about 2–4 times lower than those in black soil [38, 39].

The low nutrient is one of basic sodic soil characteristics in study areas because the soil organic matter input is limited. The maximum value of above net primary production in the region was 493.5 $g\,m^{-2}$ in undisturbed meadow steppe soil [40]. However, in recent 30 years, most of pasture ecosystem in this region was rapidly destroyed because of overburden of grazing, mowing, and cropping. The vegetation covering percentage was down from around 85% in 1950s to around 50% at present, seriously, particularly to around 10% in some grazed areas [41]. There were more than 30% alkaline spots, which nearly had no plant grew, occupying 30% of total area in the study area [35]. Additionally, structural problems of saline sodic soils would affect plant root penetration [3–5]. All the factors mentioned were contributed to the low nutrients in saline sodic soil.

3.2 Salinity, sodicity, and pH

Mean EC in the 0–50 cm soil layers ranged from 0.61 to 0.89 $dS\,m^{-1}$ with relative low values in the top soil layer (0–10 cm). The average soluble ion concentration in the topsoil was 11.38 $mmol\,L^{-1}$ for Na^+, 1.21 $mmol\,L^{-1}$ for Ca^{2+}, and 0.40 $mmol\,L^{-1}$ for Mg^{2+} (Tab. 2). High SAR existed in the layers 10–50 cm with the mean value of 16.67 in

Table 1. Statistics of nutrients in the saline sodic soils.

Nutrients	Depth (cm)	Sample size	Mean	SD	CV (%)	Min.	Max.	Range
TN ($g\,kg^{-1}$)	0–10	17	0.64	0.17	0.27	0.40	0.97	0.57
	10–30	17	0.66	0.27	0.41	0.41	1.36	0.95
	30–50	17	0.62	0.28	0.45	0.27	1.46	1.19
TP ($g\,kg^{-1}$)	0–10	17	0.24	0.07	0.28	0.16	0.39	0.23
	10–30	17	0.23	0.05	0.20	0.16	0.35	0.19
	30–50	17	0.21	0.06	0.29	0.14	0.42	0.28
TK ($g\,kg^{-1}$)	0–10	17	21.36	1.98	0.09	18.00	24.50	6.5
	10–30	17	21.15	2.61	0.12	17.30	26.90	9.6
	30–50	17	19.75	2.04	0.10	16.00	22.30	6.3
TOC ($g\,kg^{-1}$)	0–10	17	5.29	2.78	0.53	1.80	10.90	9.1
	10–30	17	5.53	3.48	0.63	1.40	14.40	13
	30–50	17	4.18	3.33	0.80	1.60	14.00	12.4
AN ($mg\,kg^{-1}$)	0–10	6	43.40	31.85	0.73	8.40	95.76	87.36
	10–30	6	39.48	29.02	0.73	15.12	92.40	77.28
	30–50	6	65.24	43.62	0.67	16.80	126.00	109.2
AP ($mg\,kg^{-1}$)	0–10	6	14.79	10.81	0.73	5.10	35.60	30.5
	10–30	6	18.08	10.70	0.59	2.75	34.75	32
	30–50	6	17.52	11.65	0.67	8.95	40.45	31.5
AK ($mg\,kg^{-1}$)	0–10	6	273.20	76.46	0.28	219.10	415.00	195.9
	10–30	6	311.42	140.66	0.45	162.20	488.20	326
	30–50	6	296.52	95.88	0.32	212.50	456.9	244.4

Table 2. Statistics of salinity and sodicity in the saline sodic soils in the west of Jilin province ($mmol\,L^{-1}$).

Depth (cm)	Statistics	Na^+	Ca^{2+}	Mg^{2+}	pH	EC ($dS\,m^{-1}$)	SAR	Alkalinity	RSC
0–10	N	26	26	26	26	26	26	26	26
	Mean	11.38	1.21	0.40	9.55	0.61	9.67	9.08	7.47
	SD	6.57	0.59	0.30	0.76	0.44	6.58	4.42	4.28
	CV (%)	0.58	0.49	0.75	0.08	0.72	0.68	0.49	0.57
10–30	N	26	26	26	26	26	26	26	26
	Mean	17.75	1.59	0.37	9.87	0.89	16.67	13.63	11.68
	SD	7.58	1.25	0.33	0.65	0.48	16.85	6.24	5.33
	CV (%)	0.43	0.79	0.88	0.07	0.54	1.01	0.46	0.46
30–50	N	26	26	26	26	26	26	26	26
	Mean	16.47	1.43	0.34	9.80	0.87	13.66	11.09	9.31
	SD	8.75	0.90	0.29	0.61	0.50	8.36	5.85	5.01
	CV (%)	0.53	0.63	0.86	0.06	0.58	0.61	0.53	0.54

10–30 cm and 13.66 in 30–50 cm. The alkalinity and RSC also showed a similar distribution pattern down to 50 cm. However, the soil presented strong alkali reactions all through the profile with pH over 9.5. These investigations proved that the soil in the area was a sodic soil bearing low salinity in the top layer and high sodic layer in the subsurface. The significant profile difference can be concluded for high coefficients of variance in soil salinity and sodicity parameters except for pH in each layer. By the chemical analysis results of soil solution, the soil can be characterized as carbonate alkaline sodic soil.

Saline sodic soil formation and development were mainly controlled by meteorological factors and groundwater chemistry as well as freeze-thaw cycle. Figure 2 shows that the seasonal change of precipitation and evaporation in the west of Jilin Province. The high evaporation to precipitation ratio drove salts moving up with water through soil capillarity. Moreover, the shallow groundwater in this area was characterized as HCO_3^-—Cl^-—Na^+—Ca^{2+} or HCO_3^-—Cl^-—Na^+ dominated under mean pH 7.43 and mean EC 2.55 mS cm^{-1}. The concentrations of HCO_3^- and Na^+ were 13.44 and 18.26 mmol L^{-1}, respectively (Tab. 3).

Besides, freeze-thaw contributed to Na^+ accumulation in the surface soil (Fig. 3). On the basis of monitoring data, the soil frozen depth was 127–178 cm and the frozen time was more than 6 months in a year in the study area. The water–salt movement regime can be described as that, in spring, frozen soil begins to melt and soluble ions in water entered into soil (Fig. 3). After evaporation, salts were left in the topsoil. The pH value in the soil above frozen layer was 0.3–0.5 higher than that in the soil below frozen layer [42]. The water containing a high concentration of salt was leached down in summer because of concentrated rain (70–80% of total precipitation). As a result, the topsoil salinity during this period was lower than that in spring and autumn. However, the shallow water table goes up and usually exceeds the critical depth (220–350 cm) because of rain and thawed water supplied [41]. The shallow water table of 40–100 cm was observed in August–September 2005 in this region. Salt accumulation in soil surface occurred in autumn due to high evaporation and low precipitation. In winter, most of salts were stored in ice and others were separated out and fixed in the surface soil when soil solution was saturated before frozen under low

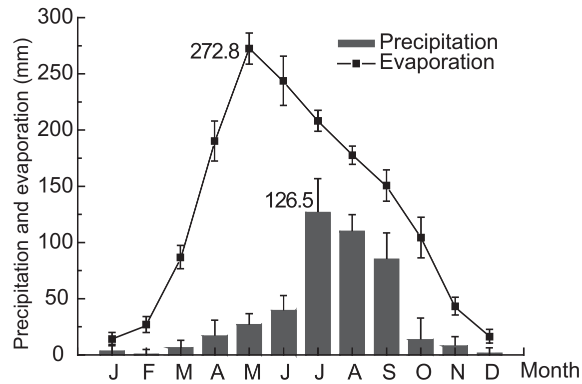

Figure 2. The seasonal variation of precipitation and evaporation in the west of Jilin province.

Table 3. Selected chemical properties of shallow groundwater in the sodic soil area in the west of Jilin Province (mmol L^{-1}).

Statistics	Na^+	Ca^{2+}	Mg^{2+}	pH	EC (dS m^{-1})	SAR	Alkalinity	RSC
N	16	16	16	16	16	16	16	16
Mean	18.26	2.30	2.23	7.43	2.55	9.60	13.44	8.91
SD	9.55	2.24	1.99	0.32	1.52	3.51	3.51	3.92
CV (%)	0.52	0.97	0.89	0.04	0.60	0.37	0.26	0.44

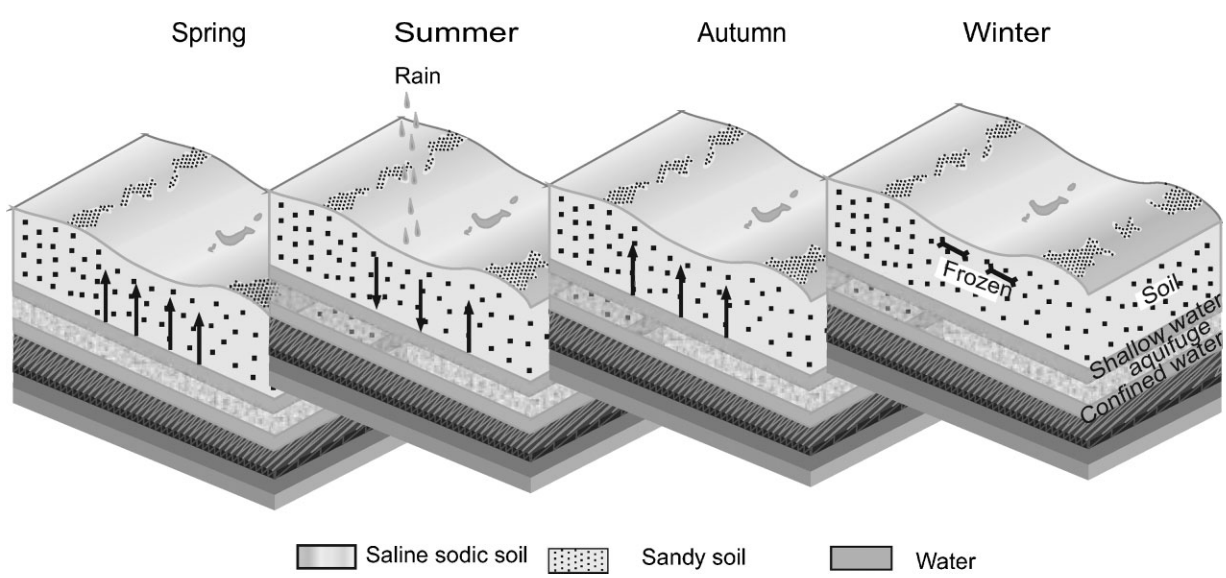

Figure 3. The sketch of seasonal movement of salt and water in saline sodic soil profile.

temperature. It was reported that the salinity in thawing soil in early spring was much higher than that in frozen soil in early winter [42]. Therefore, the periodic cycles of spring drought and groundwater level fluctuation speeded up salts accumulation in the surface soil.

3.3 The strategies of saline sodic soil management

The saline sodic soil in the west of Jilin Province, Northeast China, was characterized as low nutrient and high salinity and sodicity. To tackle these problems, it is necessary to take a better way of assembly and integration of adaptable techniques. On the basis of long term field studies and demonstration works in the region, we proposed the following reclamation strategies.

3.3.1 Amelioration saline sodic soil with sand

Sand covering can improve the physical properties of saline sodic soil. Three test levels, heavily, middle, and light, were designed for experiment of amelioration saline sodic soil using sand covering. The sand applications for heavy level, middle level, and light level were1050, 900, and 750 $m^3\,ha^{-1}\,a^{-1}$, respectively. After 3 years of continuous sand covering, the soil pH decreased from 9.08 to 7.21, Na^+ content decreased about 50%, the soil salinity, and alkalinity decreased from 0.63 to 0.37% and from 0.24 to 0.12%, respectively, in 0–30 cm soil layer for heavy level test (Tab. 4). The results indicated that the effect of desalinization was much better and pH decreased rapidly when much sand applied. The field observation found that the rice growth status was best under heavy level test among sand covering treatments. Comparing with yields under middle level test, light level test, and blank, the yield under heavy level test increased 558, 759, and 2603 $kg\,ha^{-2}$, respectively. It is possible reason that the principle of sand application is similar with function of coal fly ash [17, 23]. The soluble Na^+ should be leached out of the root zone rapidly. At end the soil physical and chemical properties were improved as soluble Na^+ was drained and soil pH was down. Within research area, the sand is accessible to obtain and transport as about 15.39% area of west Jilin Province is sandy soil distribution area [43]. So amelioration saline sodic soil with sand in this area is really feasible for its efficiency and low cost [19].

3.3.2 Farm yard manure application

Farm yard manure (FYM) is a readily available amendment in the region owing to its rich nutrient elements such as N, P, and K, etc. and the humus acid that can effectively lower soil pH and improve soil physical structure. Application of FYM resulted in increased concentrations of nutrients and organic matter as well as decreased salinity and sodicity. After 3 years of continuous FYM application of 12 $t\,ha^{-1}\,y^{-1}$, the soil pH was down from 9.08 to 7.61, organic mater increased from 1.3 to 2.1%, available N and P increased to 47.0 and 19.3 $mg\,kg^{-1}$. The rice crop yield increased at 76.5% with FYM application compared with no FYM application treatment. The principle of reclamation processes can be explained with that soil organic addition can activate soil microbes to produce organic acids neutralizing soil alkalinity. Moreover, soil physical structure was improved and more efficient salt leaching was obtained with soil organic addition [35]. Further study, we observed that growth and yield of rice under treatment of sand cover together with FYM application were better than that of sand covering treatment or FYM application alone. The yield of heavy sand cover with light FYM application (3 $t\,ha^{-1}\,y^{-1}$) was 7468 $kg\,ha^{-1}$, which was 1468 and 1684 $kg\,ha^{-2}$ higher than that of heavy sand covering treatment and light FYM application treatment, respectively. In the view of feasibility, FYM application can be used as a sustainable practice for the saline sodic soil reclamation because it is rich in resource and low in cost in this area.

3.3.3 Salt tolerant grass revegetation

Soil physical and chemical properties can be improved by growing salt-tolerated plant species [11, 26, 27]. Previous studies showed that plants could decrease soil pH [25, 26] and ESP [25–28], increase soil organic matter, nutrients [29, 44], and soil conductivity [9, 28]. There were 74 halyphyte species reported in the region which could be potentially used as the pilot reclamation plants including *Suaeda corniculata*, *Chloris virgata*, *Puccinellia tenuiflora*, *Leymus chinensis*, etc. Depending on the severity of soil salinity and sodicity and plant salt/sodium tolerance, we selected adaptable species for revegetation. For the severe degraded region (soil salt content: 1.0–2.0%, pH: 9–11), *P. tenuiflora*, a high salt tolerant native perennial species, was artificially established with intensive irrigation, resulting about 70% desalinization in the top 20 cm of the soil profile was obtained after 3 years. For the moderate degraded region (soil salt content: 0.3–0.4%, pH: 8–8.5), *L. chinensis*, a native high quality pasture plant, was regenerated through deep plowing and direct seeding and the hay of 2 $mg\,ha^{-1}$ was achieved. For the slight degraded region (soil salt content: 0.1–0.3%, pH: 7.5–8.0), alfalfa (*Medicago sativa*), a deep rooted leguminous perennial forage crop, was planted. The results showed that the desalinization of 17.1% for 0–10 cm, 10% for 10–30 cm soil layer was reached after 3 years. Salt tolerant species revegetation not only improved saline sodic soil physical and chemical properties, but had economic significance since most of these species could provide high quality forages.

3.3.4 Leaching with groundwater and growing rice

Irrigated rice cropping was practiced to reclaim alkali-sodic soils in many parts of the world [14, 35]. Rice was the crop best suited to saline lands because the standing water which was necessary for leaching the salts caused chemical changes in the soil which was benefit for rice [19]. Biologically, rice was classified as moderately sensitive to salinity and as tolerant and moderately tolerant to sodicity [14, 19]. On the high ESP soils in the west of Jilin province,

Table 4. Chemical elements in soil treated by sand cover. A1, heavy level test; A2, middle level test; A3, light level test.

Test level	Ca^{2+} ($mg\,kg^{-1}$)	Mg^{2+} ($mg\,kg^{-1}$)	Na^+ ($mg\,kg^{-1}$)	Salinity ($mg\,kg^{-1}$)	Alkalinity ($mg\,kg^{-1}$)	pH
A1	175.3	91.2	240.6	1734.8	822.0	7.2
A2	150.3	136.8	494.5	2663.1	1281.0	7.4
A3	200.4	45.6	619.8	2793.5	1281.0	7.6
Blank	225.5	152.0	489.4	3025.8	1464.0	9.1

Northeastern China, rice is cropped with groundwater condition for the whole growing season. Field monitoring data showed that the concentrations of Na^+, Ca^{2+}, and Mg^{2+} in 30 cm topsoil decreased to 56.6, 69.1, and 87.9% of initial values, respectively. After 5 years rice cultivation, soil pH and ESP of 0–15 cm layer in top soil decreased from 8.94, 41.7 to 8.42, 4.5, respectively. The rice yields of first, second, and third year were about 120, 980, and 2070 kg ha^{-2}, respectively. The results show that the method is much effective for reclamation of saline sodic soil. Luo and Sun [37] reported the average salt concentration of top soil (heavy salinized meadow soil) in depth of 30 cm decreased from 0.45 to 0.15% after 4-year experiments using surface water for irrigation. The main reason of decreased Na^+ in soil was that the groundwater for irrigation was rich of Ca^{2+} and exchangeable Na^+ was replaced by soluble Ca^{2+}. The deep plough accelerated the exchange reaction between Ca^{2+} and soil's exchangeable Na^+. At last the soluble Na^+ was out of experimental zone following bathed water and soil pH was down. However, we observed that soil pH and ESP of 30–45 cm layer in the soil profile increased from 8.94, 12.3 to 9.25, 38.2, respectively, indicating a desalinization processes in the upper layer of soil occurred under the leaching with groundwater. It should be noted that this reclamation was achieved with the integration of well-established irrigation and drainage systems, organic material fertilization, and planting salt tolerant rice varieties. In the studied area, the groundwater resource is rich though the region locates in arid and semi arid area. The total groundwater reserve is about $91.5 \times 10^9\,m^3$. The groundwater thickness is 10–45 m and 2–5 m below surface [41]. The water chemical type is HCO_3^-—Na^+—Ca^{2+}; the mineralization degree is 0.3–0.82 g L^{-1} and pH value 6.8–7.3. The quality of ground water is good and suitable for irrigation.

4 Concluding remarks

The investigations of the saline sodic soil properties were carried out and characterizations of the problem soils were documented in the west of Jilin province. The data showed that the soils have low nutrient content such as organic carbon, nitrogen, phosphorus, and high content of salt in the soil solution and exchangeable sodium on soil particles. The sodium carbonate and bicarbonate salts move up and accumulate in the topsoil under the local climate, shallow water level seasonal fluctuation, and freeze-thaw process. The strategies of saline sodic soil reclamation and management were proposed. Sand and FYM application is a feasible practice for the soil reclamation and improvement because both are rich in resource and low in cost in the region. With salt tolerant grass revegetation scenario, we need categorize the soils into severe, moderate, and slight in salintiy and sodicity first, and then take into account the salt tolerant grass species and its economic significance. Leaching with groundwater and growing rice is experienced as a gradual way of reclamation of saline sodic soil in the region.

Acknowledgments

The authors gratefully acknowledge financial support from the Chinese Academy of Sciences (kzcx2-yw-223), the 100 Talents Program of the Chinese Academy of Sciences, the Science and Technology Development projects of Yantai City (2008155), the CAS/SAFEA International Partnership Program for Creative Research Teams, the Natural Science Foundation of China (grant # 40873062), and the Science and Technology Development Program Project of Shandong Province (2008GG20005006 and 2008GG3NS07005). Two anonymous referees and Editor H. Shao are sincerely thanked for constructive comments and suggestions, which were helpful to us in improving our manuscript.

The authors have declared no conflict of interest.

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